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Progress Report

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Enhanced Surveillance Program

FY97 Accomplishments

Los Alamos
NATIONAL LABORATORY

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Abstract

This report highlights the accomplishments of the Enhanced Surveillance Program (ESP), the highest-priority research and development effort in the United States' management of its stockpiled nuclear weapons. It is Volume 1 of 11, the unclassified summary of selected program highlights. These highlights fall into the following focus areas: pits, high explosives, organics, dynamics, diagnostics, systems, secondaries, materials-aging models, nonnuclear materials, nonnuclear components, and routine surveillance testing systems upgrades. Principal investigators from around the DOE Complex contributed to the report.

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Enhanced Surveillance Program

FY97 Accomplishments

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Acronyms and Terms

AAU	accelerated aging unit
ADAPT	Advanced Design and Production Technologies Program
ASCI	Advanced Strategic Computing Initiative
AS-FM&T	Allied Signal-Federal Manufacturing and Technology
CCD	charge-coupled diode
CDU	capacitive discharge unit
CEC/MS	capillary electrochromatography using ion-trap mass spectrometry detection
CSA	canned subassembly
CSP	Core Surveillance Program
DES	data encryption standard
DLO	diffusion-limited oxygen
DOE	Department of Energy
DSC	differential scanning calorimetry
EFI	enhanced fidelity instrumentation
ESNet	Energy Science Network
ESP	Enhanced Surveillance Program
fcc	face-centered cubic (metallurgical structure)
FPGA	field-portable gas analyzer
FTIR	Fourier Transform Infrared Spectrometer
FY	fiscal year
GC	gas chromatography
GC/MS	gas chromatography/mass spectrometry
HE	high explosive
HEAF	High Explosives Application Facility
HERT	high-explosive radio telemetry
hydro	hydrodynamic
IMC	intermetallic compound
JTA	joint test assembly
KC/KCP	Kansas City Plant
LA/LANL	Los Alamos National Laboratory
LANSCE	Los Alamos Neutron Science Center
LC/MS	liquid chromatography with negative chemical ionization mass spectrometry
LL/LLNL	Lawrence Livermore National Laboratory
LMES	Lockheed Martin Energy Systems
MIT	Massachusetts Institute of Technology
MIV	magnetic impulse and velocity
MW	molecular weight
NWC	nuclear weapons complex
NWIG	Nuclear Waepons Information Group
OR	Oak Ridge
OUAL	Ohio University Accelerator Laboratory
PBX	plastic-bonded explosive
PDF	pair distribution function
PLR	percent load retention
PMAP	Polymeric Materials Aging Program
PMT	photomultiplier tube
PSC	pit surface characterization
PX	Pantex Plant
RFQ	radio frequency quadrupole
R&D	research and development
RH	relative humidity
SFE	slim-loop ferroelectric (firing set)
SIMIR	surface inspection machine/infrared
SN/SNL	Sandia National Laboratories
SQUID	superconducting quantum interference device
SR	Savannah River Site
SRTC	Savannah River Technology Center
Tg	glass transition temperature
tribiological	friction, lubrication, and wear of surfaces in relative motion
UV	ultraviolet
VISAR	velocity interferometer
WR	war reserve
XAFS	x-ray absorption fine structure
XRD	x-ray diffraction/scattering
Y-12	Oak Ridge

Foreword

It is our distinct pleasure to present the accomplishments of the Enhanced Surveillance Program. The Enhanced Surveillance Program is the highest-priority research and development (R&D) effort in stockpile management today. The program provides an understanding of future weapon degradation, essential to maintaining the stockpile indefinitely in the absence of underground testing. We want to share with you some of its most important characteristics.

1. There is one Enhanced Surveillance Program that spans the entire complex. Research in this program is conducted by teams of scientists and engineers from all the labs and all the plants. The progress to date and the program's future success relies on this collaboration, requiring the combination of skills and facilities spanning the weapons complex.

2. This is a goal oriented program. As you review the progress over the last year, you will see that we are systematically addressing specific stockpile concerns through achievement of the program's predefined objectives. The program's documented milestones and deliverables drive and gauge our progress. The program balances the delivery of many low-risk, near-term tools with a few higher-risk tasks offering a potentially big payoff for the stockpile in the long term.

3. It is our intention this be a genuine expansion of surveillance R&D. All organizations in the weapons complex have done surveillance R&D throughout their history. With this program, we are placing additional emphasis on improving our surveillance capability. The Enhanced Surveillance Program Plan acknowledges the ongoing R&D efforts and seeks to demonstrate how those actions support the achievement of enhanced surveillance R&D goals.

We are very pleased with this program's progress. We commend the many investigators for their outstanding contributions, as well as the members of the Enhanced Surveillance Steering Committee for building quality teams of performers. We are confident this program will continue to be executed with vigor and success.

One Mission, One Program, One Stockpile.

Robin Staffin
Deputy Assistant Secretary
for Research and Development
Defense Programs

Gene Ives
Deputy Assistant Secretary
for Military Application and
Stockpile Management
Defense Programs

Introduction

This Annual Report

You are reading one volume of the Enhanced Surveillance Program (ESP) FY97 Accomplishments. The complete accomplishments report consists of 11 volumes. Volume 1 includes an ESP overview and a summary of selected unclassified FY97 program highlights. Volume 1 specifically targets a general audience, reflecting about half of the tasks conducted in FY97 and emphasizing key program accomplishments and contributions.

The remaining volumes of the accomplishments report are classified, organized by program focus area, and present in technical detail the progress achieved in each of the 104 FY97 program tasks.

Focus areas are as follows:
- Pits
- High Explosives
- Organics
- Dynamics
- Diagnostics
- Systems
- Secondaries
- Nonnuclear Materials
- Nonnuclear Components
- Surveillance Testing Program Upgrades

ESP in Context

The only thing remaining constant in the Nuclear Weapons Program is its mission: to maintain a safe and reliable nuclear weapons stockpile.

In the past that mission was accomplished on a large scale with growth. Stockpile systems were periodically replaced with newer and better versions, a robust design and production capacity supported both stockpile modernization and the rapid implementation of stockpile repairs, and confidence was assured with the certainty of an underground nuclear test.

Today, with the challenging constraints of producing no new nuclear weapons and conducting no underground nuclear weapons tests, the mission is founded in science-based stockpile stewardship and management. Current plans require systems to remain in the stockpile indefinitely, and therefore, confidence in the readiness of the stockpile now includes an uncertainty driven principally by aging.

The Enhanced Surveillance Program (ESP) is central to the new strategy, focused on understanding and predicting the effects of aging, and ultimately reducing uncertainty.

As you read this report, keep in mind that ESP contributions transcend stockpile management. The new materials and aging information gained from the ESP supports much more than just predicting component failures and scheduling repairs. This information extends the knowledge base supporting component design, fabrication, certification, safety analysis, surveillance, and dismantlement. With this new knowledge, our confidence in all aspects of stockpile support can be firmly anchored to a broader and deeper scientific base, making the Enhanced Surveillance Program a key component of science-based stockpile stewardship and management.

Also, remember that the ESP is an important element of stockpile life extension. The Stockpile Life Extension Program, DOE's planning framework for proactive management of system maintenance activities, relies on ESP to provide the technical basis for component reuse decisions during refurbishment and to provide the diagnostics required to detect degradation of components before they fail.

The ESP has implemented a strategic vision, based on requirements and focused on the stockpile. The program exploits resources and capabilities across the weapons complex. We measure our progress against defined performance expectations as documented in the ESP Program Plan. This report is just one example of how ESP documents the delivery of results.

David V. Feather
Enhanced Surveillance Program Manager
Office of Defense Programs
U.S. Department of Energy

Overview

The objective of the ESP is to develop tools, techniques, and procedures to advance the capabilities of the Department of Energy (DOE) to measure, analyze, calculate, and predict the effect of aging on weapons materials, components, and systems and to determine if and/or when these effects will impact weapon reliability, safety, or performance. These tools, techniques, and procedures are elements of two major ESP deliverables: augmentation of the department's core surveillance program with age-focused diagnostics and prediction of service lives of safety and reliability components.

The ESP is an essential element of the United States' strategy for efficiently maintaining a safe and reliable nuclear deterrent. Over the last decade, the nuclear weapons program has changed in two significant ways: a policy of extending the lifetime of existing stockpile weapons (hence, no new weapon production) has been adopted, and the nuclear weapons complex has been streamlined, drastically reducing both capacity and capability. The weapons complex now relies on careful planning and scheduling to conduct the required component production, surveillance, and maintenance with diminished resources.

The tools provided by the ESP alleviate the uncertainty of the future. The conclusions of the program serve to validate or dismiss concerns about weapons component failure and to identify previously unknown aging impacts. With early identification of age-related failure mechanisms (through predictive models and age-focused diagnostics) the program enables efficient strategic planning, minimizing the demands for infrastructure and other resources and ultimately reducing the threat to national security. Finally, investments in ESP are recovered when conclusions indicate components or materials do not require replacement.

The activities under this program are carried out at the DOE weapon production plants and design laboratories—the Kansas City Plant (KC), Y-12 Plant (also termed "OR" for Oak Ridge), Savannah River Site (SR), Pantex Plant (PX), Los Alamos National Laboratory (LA), Lawrence Livermore National Laboratory (LL), and Sandia National Laboratories (SN). There is strong coordination and teaming among the laboratories and production sites for the planning, selection, and conduct of research projects for this program.

Enhanced Surveillance Program Funding Profile

FY96	FY97	FY98	FY99
$28.8M	$75M	$60M	$68M

The ESP represents a bridge between the Defense Programs Office's current core R&D and stockpile surveillance programs and provides the necessary predictive models and age-focused diagnostics required to anticipate weapon refurbishment. The program is a necessary precursor of Stockpile Life Extension Program planning. The materials and component service-life predictive capabilities resulting from ESP are focused on anticipating stockpile defects, allowing timely remedial action and refurbishment planning.

The ESP sponsors applied research and development related to the effects of material and component aging. The program leverages work conducted through core R&D and other initiatives such as Advanced Design and Production Technologies (ADAPT) and the Advanced Strategic Computing Initiative (ASCI) program. Examples of capabilities ESP is enabling include new age-focused system, component and materials performance tests, new flight test configurations, materials characterization and modeling, nondestructive evaluation, and modeling of the weapon aging process to the extent practicable.

Program Goals

As has been stated, the objective of the ESP is to provide advanced capability to measure, analyze, calculate, and predict the effects of aging on weapons materials and components and to understand these effects on the reliability, safety, and performance of existing weapons beyond their original design life.

Specific ESP goals include
- Predicting component and material failure mechanisms
- Predicting materials, components, and systems service lives
- Determining the feasibility of monitoring critical components in place, in real time, nondestructively
- Developing diagnostics for failure mechanisms whose failure time cannot be adequately predicted

The ESP plans to achieve the above goals by
- Developing techniques for advanced analysis of existing surveillance data, including archived data handling and data access
- Performing research and development on existing and old stockpile materials and components
- Developing experimental tests to enhance data for establishing baseline properties and performance of weapons materials/components to facilitate failure prediction by understanding changes caused by aging and other agents (e.g., corrosion and hydriding) in the baselines
- Conducting pilot development programs on selected components and/or stockpile systems to ensure the viability, usefulness, and cost-effectiveness of new surveillance techniques/technologies
- Once proven, introducing new techniques/technologies into the core stockpile surveillance program and into the production complex as appropriate
- Identifying new facilities, equipment, capabilities, and sensors needed to detect potential problems during the conduct of ESP R&D.

Enhanced surveillance efforts will augment core surveillance program activities, primarily in the evaluation of aged materials and components. Based on laboratory and plant efforts to analyze potential weak points in the current stockpile, ESP also extends the core surveillance strategy by mandating pilot implementation of new techniques and technologies into core stockpile management activities.

Program Tactics

During the conception phase of the ESP, a committee composed of nuclear weapon design and production subject matter experts reviewed each major subsystem within a generic weapon system (i.e. primaries, secondaries, and nonnuclear components) to determine where surveillance capabilities and technologies required enhancement. This assessment is validated annually. Within the three focus areas (primaries, secondaries, and non-nuclear components), the results of the assessment fell into six categories

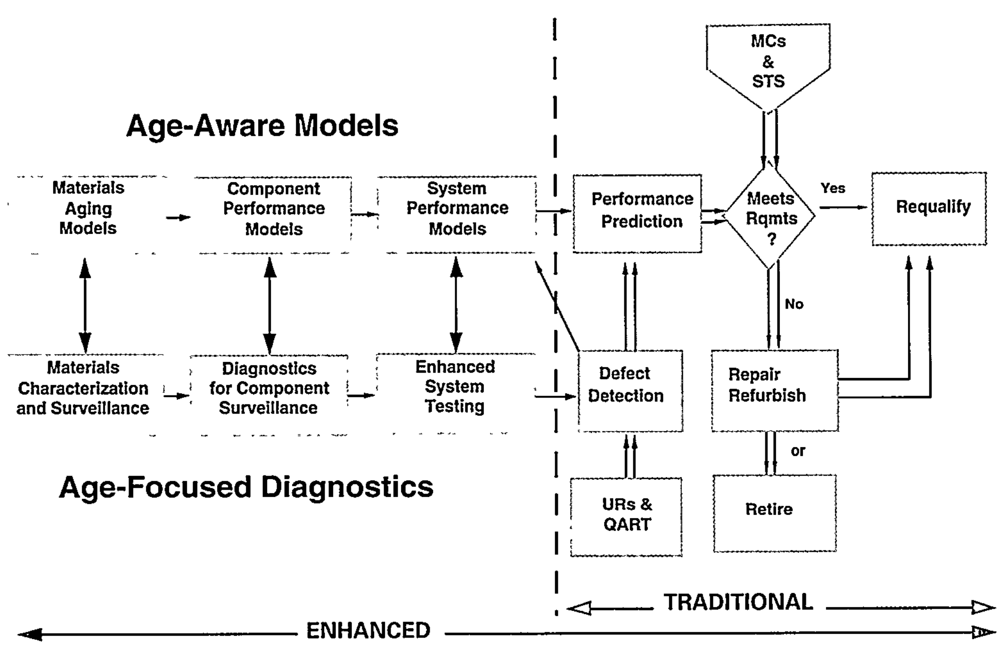
- Material characterization and surveillance
- Materials-aging model development
- Component performance models
- System performance models
- Component surveillance and diagnostics
- Enhanced system testing

The figure below depicts the DOE's surveillance program. Enhanced surveillance provides age-focused diagnostics and age-aware models as an augmentation to traditional surveillance testing and performance prediction.

Those areas covered by the traditional core surveillance program are shown on the right side of the diagram. The ESP is shown on the left of the dashed line. The ESP, as integrated with the traditional surveillance program, forms a coherent approach toward the goal of maintaining a reliable and safe stockpile.

The ESP was constructed to be a short-term (5–7 year), rapidly evolving R&D effort directed by an ESP steering committee. The ESP Program Manager reviews and authorizes all projects. Less fruitful projects are terminated, and new advanced research concepts are added to the program through the steering committee review and authorization process. Full-scale implementation of ESP technologies into the core surveillance program occurs when those technologies are demonstrated and determined essential.

There are many examples of the products the ESP will deliver. These products range from performance forecasts on critical stockpile components and assemblies, and the demonstrated early identification of life-limiting developments, to the deployment of new surveillance and assessment tools, and identification of the key signatures of aging. In summary, the program provides the technical basis for risk-management decision making.



Pit

Focus Area

The Pit Focus Area assesses the effects of aging on the safety and reliability of pits. Tasks in this area include material studies, theoretical models, and system-level performance assessments. Material studies investigate the effects of aging on static and dynamic properties of pit materials in both engineering and nuclear applications. Physical measurements of material properties combined with experiments are used to assess effects on aspects of physics performance. New theoretical models provide a basic understanding of aging that will lead lifetime predictions for pits. System-level experiments are being conducted to assure the validity of predictions and the safety and reliability of the pits in the stockpile.

Analysis, prediction, and mitigation of aging effects in pits, specifically in plutonium, are key to enduring long-term safety and reliability. Changes resulting from aging are expected in fundamental properties such as composition, crystal structure, and chemical potential. These changes may lead to changes in engineering and physics performance characteristics such as equation of state, spall and ejecta formation, strength, density, geometry, corrosion resistance, and nuclear reactivity. Aging mechanisms that cause these potential changes include the in-growth of decay products, uranium recoil damage and associated void formation, phase stability concerns, changes in surface chemistry, and a variety of environmental changes including thermal cycling. Development of advanced characterization tools to measure changes in these properties is essential. The resulting data analysis will expand our nuclear materials knowledge base and form the basis for computational models necessary for predictive assessment.

Deliverables

1. Measure and characterize the products and nature of corrosion processes occurring during weapon lifetimes.
2. Define the chemistry and stability of the gas phase and its relationship to corrosion kinetics.
3. Identify important aging phenomena (e.g., helium in-growth) and develop procedures to monitor and evaluate those changes within the Pit Surveillance Program.
4. Obtain stress-strain mechanical property data at intermediate and high strain rates on baseline weapons materials and stockpile-returned plutonium and uranium to understand the compressive deformation response of these materials as a function of aging.
5. Measure the x-ray absorption fine structure (XAFS) spectra, synchrotron radiation-based x-ray diffraction/scattering (XRD) patterns, and neutron scattering patterns, of baseline plutonium alloys, aged plutonium samples, and other plutonium.
6. Develop models of the plutonium metal aging process with the ultimate goal of predicting lifetimes by providing physics input for high-performance codes to be developed under the ASCI Program.
7. Use high-flux x-ray synchrotron radiation microdiffraction to nondestructively measure residual stress with micrometer-size spatial resolutions within pit materials.
8. Measure elastic moduli in a broad temperature range for new and aged polycrystalline and single-crystal samples of plutonium, and correlate structural and mechanical properties with age.
9. Predict and measure directly (using laser-interferometric techniques) the dimensional changes occurring in aged plutonium as a result of helium accumulation, radiation damage, and resultant void formation.
10. Determine the nature of irradiation-aging-induced defects (distribution of voids, vacancies, and other microstructural characteristics) in the microstructure of plutonium using positron annihilation spectroscopy defect analysis.
11. Experimentally assess effects of aging on ejecta, spall, and equation of state.
12. Assess results of any potential changes in ejecta, spall, and equation of state on primary performance for stockpile weapons.

Pertinent Tasks

- **LA09** The Miniflyer (Pu & U)
- **LA11** Pu Surveillance R&D Support
- **LL03** Experimental Studies of Ejecta and Debris
- **LA12** Dynamic Behavior of Pu & U (Intermediate Strain Rate)
- **LL30** Positron Annihilation Studies of Aged Pu
- **LA29** Modeling Stability of Aged Pu
- **LL01** Modeling of Void Formation and Other Aging Mechanisms
- **LA13** XAFS/XRD to Measure Microscopic Material Stability
- **LL02** Decay-Induced Swelling of Pu
- **LA34** Resonant Ultrasound Study of Pu Aging
- **LA32** X-Ray Synchrotron Radiation Measurements of Residual Stress

LL02 Decay-Induced Swelling of Plutonium

The objective of this task is the high-precision (≤ 5 nm), long-term measurement of possible length changes that may be due to alpha-decay-induced swelling in plutonium samples. We have designed and built a prototype system. Evaluations show it has the accuracy required to detect potential early indications of swelling. These measurements will be made using laser interferometry, and plutonium samples will be housed in a vacuum system during the length change measurements. Current plans call for starting these measurements in the Pu facility at Livermore in FY98 using aged samples. Some of the aged samples are obtained from old pits, and one is obtained from the United Kingdom and machined at Los Alamos.

Work in FY97 has been focused on performing a laboratory evaluation of our measurement strategies using a scaled-down, single interferometer version of the multiple sample/interferometer system planned for implementation in the Pu facility. This single system was designed and built during FY97, and it has all the critical measurement and sample design features of the full system. Therefore, experience with this prototype system is expected to provide information critical to improving the full system when it is built.

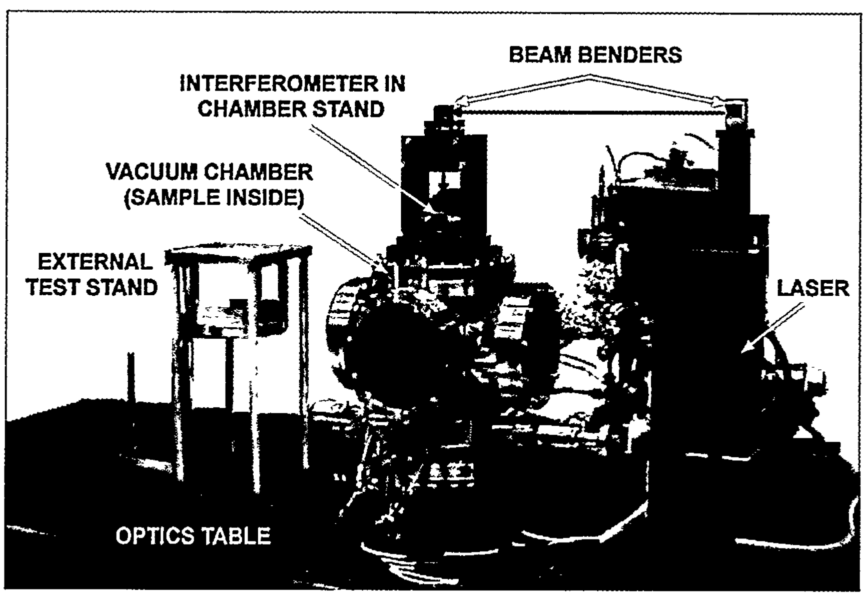


Figure LL02. *Single-interferometer system on optics table.*

The figure is a recent photograph of this single-interferometer system, located at Sandia National Laboratories, California. All custom hardware and optics materials for the system have been designed and fabricated and have undergone initial assembly testing. The vacuum system and all related parts are assembled and running. Test samples (nonplutonium) whose length changes will be measured will be located inside of the ion-pumped vacuum system (currently operating at pressures <2 x 10^{-8} torr), which is mounted on a vibrationally isolated optics table. This degree of atmosphere control is required to prevent corrosion of the sample that might interfere with measurement. The interferometer has a base precision of 5 mm and temperature control of less than 0.08 °C.

Current activities in this project are focused on testing the interferometer system, using the external test stand shown in the photograph, and improving software used for both interferometer control and temperature data acquisition. Following these preliminary tests, length changes in nonplutonium samples will be measured initially on the external test stand and then inside the vacuum chamber. The project is on schedule. With sufficient funding, the current work will result in the final design and construction of the full interferometer system and commencement of plutonium measurements in FY98.

Miniflyer Program

The Miniflyer Program is the development for laser-launching miniature (25-100 µm x 3-mm) flat (1-D) flyer plates for the purpose of generating and collecting dynamic property measurements of samples of returned pit materials, especially Pu. The miniflyer offers several advantages over conventional experimental methods including the collection of dynamic data not currently available, reduced cost, ease and versatility of experiments, and safety. The miniflyer can use pit samples as targets without preparations that might alter the mechanical properties of the samples.

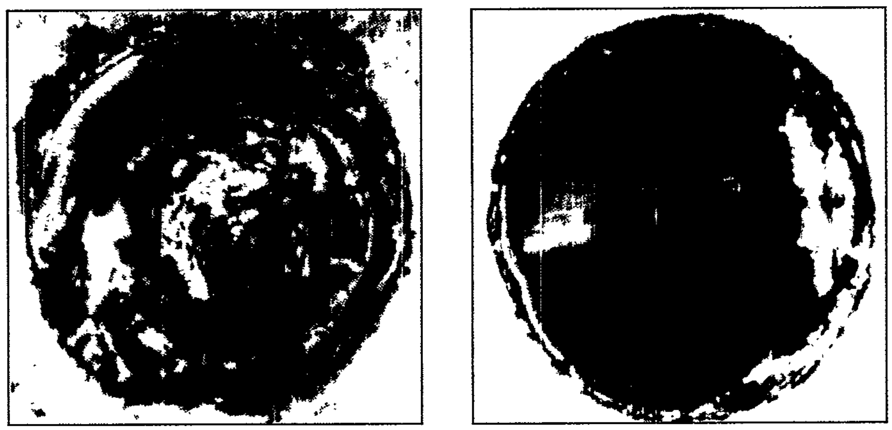


Figure LA09. *Special diffractive optics were designed, fabricated, and tested to convert a high-power, high-energy laser pulse from a spatial Gaussian to a "top hat" for one-dimensional plate launch.*

Miniature laser-launched flyer plates are ideal for generating nearly one-dimensional shocks in materials where the thin and small-size flyer plates and/or targets offer the advantage of precise location of stress profiles at high strain rates. By varying target thickness and material, we can experimentally determine a wide variety of dynamic, mesoscale material properties that cannot be readily assessed by more traditional experimental methods. Unlike other laser-generated shock methods, the use of laser-launched plates decouples plate launch from plate impact, and therefore from the shock generated in the target. The laser-launched plate is a smaller version of an explosive or gun-launched plate and for most technical considerations is identical. The small size and thus short shock duration and release permit placing interfaces under tensile stress without significantly stressing either side of the interface and without the normally accompanying collateral damage from sabots and/or residual energy. By using various experimental designs, we can determine equations-of-state, spall strength at high strain rates (10^4–10^8 sec^{-1}), and other dynamic properties. The small size of the miniflyer and target requires improved temporal resolution for dynamic experiments. Velocity interferometer signals are recorded using optical fibers and an electronic streak camera instead of the more traditional photomultiplier tubes. By using fibers and a streak camera, we can improve the temporal resolution from 3–5 ns to <100 picoseconds. An improvement by more than an order of magnitude in temporal resolution permits quality data on small, thin samples.

As Pu ages, dislocations, helium at grain boundaries, decay products, and contamination can alter the metallographic and mechanical characteristics of the Pu, the Pu surfaces, and Pu interfaces. These types of material aging need to be quantified to ensure an enduring stockpile. Miniflyer experiments will compliment and add to the technical database with critical dynamic pit performance data that cannot be obtained by other methods. By relating the aging effects with the dynamic performance, we may be able to quantify the useful lifetime of Pu.

LL30 Positron Annihilation Studies of Aged Plutonium

The evolution of defects resulting from radiation damage from the radiolytic decay of Pu is one of the unknown quantities affecting our confidence in predictions of the limit on stockpile components. Radiation damage leads to changes in the size and strength of metals studied for reactor and accelerator use, and similar effects may be expected in Pu. The formation and migration of radiation-produced vacancies into larger void structures or to grain boundaries may result in changes in strength or density in Pu at some age. A detailed understanding of the defects in self-irradiated Pu is required as input to models used to predict the time scale of void swelling, embrittlement, and related radiation effects. We found He-filled vacancies in new and aged material. The concentration increases with age. We found no voids that could destabilize pit dimensions.

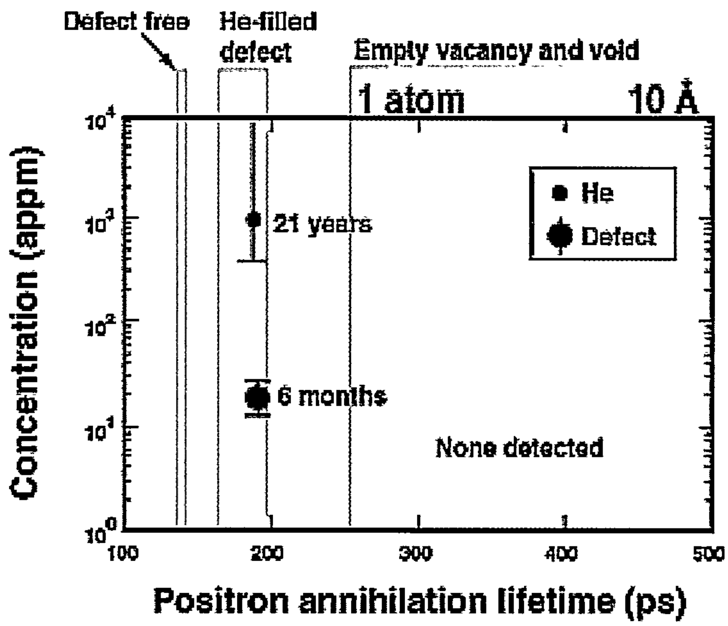


Figure LL30. *Positron lifetime values identify He-filled vacancies as the dominant defect in two Pu samples. Similar He concentrations and defect concentrations support this identification. The concentration of HE-filled vacancies increases with age.*

We made measurements of defects in war reserve (WR)-phase, Ga-stabilized Pu, using positron annihilation lifetime spectroscopy at a unique Livermore facility. Positron annihilation lifetime spectroscopy is an established tool for the analysis of vacancies and voids in metals and compounds. The correlation between lifetime and defect size can be measured and calculated with sufficiently high accuracy to differentiate between major defect classes such as vacancies, vacancy clusters, and voids. Defect concentrations can be determined from the fraction of positrons annihilating at the defect site.

An aged sample and one recently cast have been measured in their "as received" state. Identification of defect character and concentration has been accomplished for both specimens. Comparison of the positron annihilation lifetimes found in the data with calculated values suggests that He-filled vacancies or vacancy clusters dominate the defect population in both 6-month-old and 21-year-old material. The concentration of defects was determined from the positron annihilation lifetime data as well. Helium concentrations calculated from radioactive decay were similar to the defect concentration, lending further evidence that the defect observed was helium in a vacant Pu site. The concentration of He-filled vacancies was much lighter in the older material. The lack of a void signal in the aged sample shows that void growth has not yet initiated at 21 years.

A high concentration of He-stabilized vacancies or vacancy clusters is a necessary condition for void growth and swelling. Without stabilization, vacancies produced by the recoiling atoms during the radioactive decay are lost to recombination with interstitial atoms, grain boundaries, impurities, and other microstructural features. All models of void swelling proceed from the accumulation of vacancies that have been stabilized by He. Thus, in 21-year-old Pu we have found the precursor to void swelling but no evidence of voids in the samples measured.

Experimental Studies of Ejecta and Debris

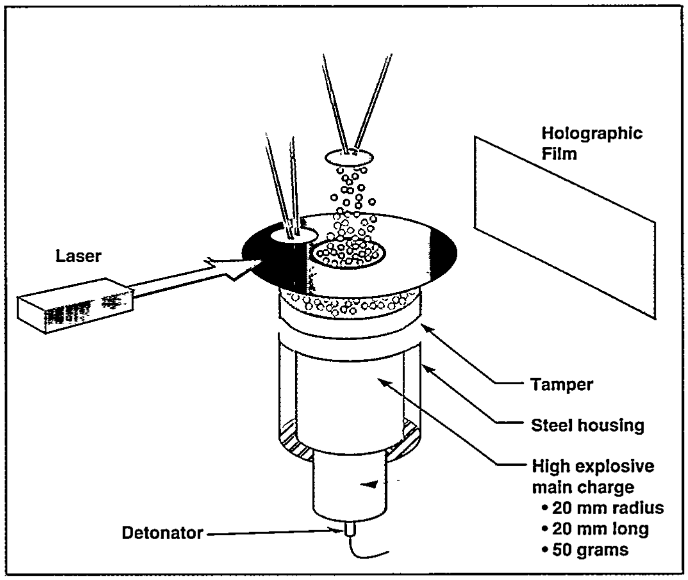


Figure LL03. *A side-on view of the cylindrical, symmetric design for the Holog experiment.*

One of the ultimate goals of the ejecta experimental program involves a direct measurement of ejecta from "aged" and "new" Pu. The first Livermore subcritical experiment ("Holog") is designed to obtain baseline information on ejecta production from new, wrought Pu (a side-on view of the cylindrical, symmetric design is illustrated in the figure.) During the course of FY97 the diagnostics were developed, and the design was tested using inert materials. A laser for holographic use was refurbished, tested, and installed in the U1a facility at the Nevada Test Site. The final integrated dry run for this experiment was performed at Livermore Site-300 (January 31, 1997) to test the total experimental assembly and the diagnostics and to verify the timing. The measured jump-off time and velocity were very well reproduced by the calculations. Recent relevant data have caused a rethinking of the designed pressure experienced by the Pu sample. The first subcritical experiment ("Rebound," conducted by Los Alamos) was executed July 2, 1997, and Holog is scheduled for execution late FY97. The execution of these experiments was delayed more than one year pending DOE approval for subcritical experiments. Several potential sources for the aged Pu sample have been identified and are currently being evaluated for use in experiments planned for FY98.

Synchrotron X-Ray Measurements of Local Structure in Plutonium Alloys

In the conventional crystalline solid model for the atomic-scale structure of plutonium an elementary, highly symmetric unit cell is propagated through space to give the exact positions of all of the atoms in the crystal as well as the crystal lattice, defined by the planes of these atoms. Traditionally, plutonium has been considered a typical face-centered cubic (fcc) metal similar to copper or platinum. Over the last ten years the understanding of crystal structure in condensed matter has been extended by the addition of "local" structure. The long-range average structure, determined from conventional analysis of diffraction peaks, remains defined as before, but some of the atoms may be displaced from their average positions on the lattice so that the coincidence between the atoms and the lattice is no longer absolute and may actually undergo substantial breakdown. The techniques of XAFS spectroscopy and pair distribution function (PDF) analysis of scattering data have been the most useful probes of local structure and have been critical in understanding the relationship between the structure and the unusual properties of materials such as the cuprate superconductors.

When these measurements are performed on delta-stabilized plutonium alloys, the results most relevant to the objectives of ESP occur in the plutonium XAFS of new and aged delta-stabilized alloys. Studies were performed on new and aged Pu and Ga content close to and far from the delta-phase stabilization composition limit. A third shell of electrons at ~3.8 Å was found in new material or material close to the delta stabilization limit. In materials that were aged or had Ga concentration far from the stabilization limit, this third shell was absent. We are currently pursuing these studies with the intent of developing a complete, predictive model for the atomic-level structure of delta plutonium that will be accurate on all length scales.

However, even in the absence of such a model for aging, we have found a single, easily identified and characterized feature in the local structure that is apparently critical in both aging and in the instability of plutonium-gallium alloys at low gallium concentrations. In addition to indicating that aging and the relatively low structural and chemical stability of low-gallium delta plutonium are intimately related, this feature can also provide a means for evaluating the extent of aging in plutonium and serve as a useful and easy probe for gauging the effects of fabrication and other parameters on the structure and properties of new and restored materials.

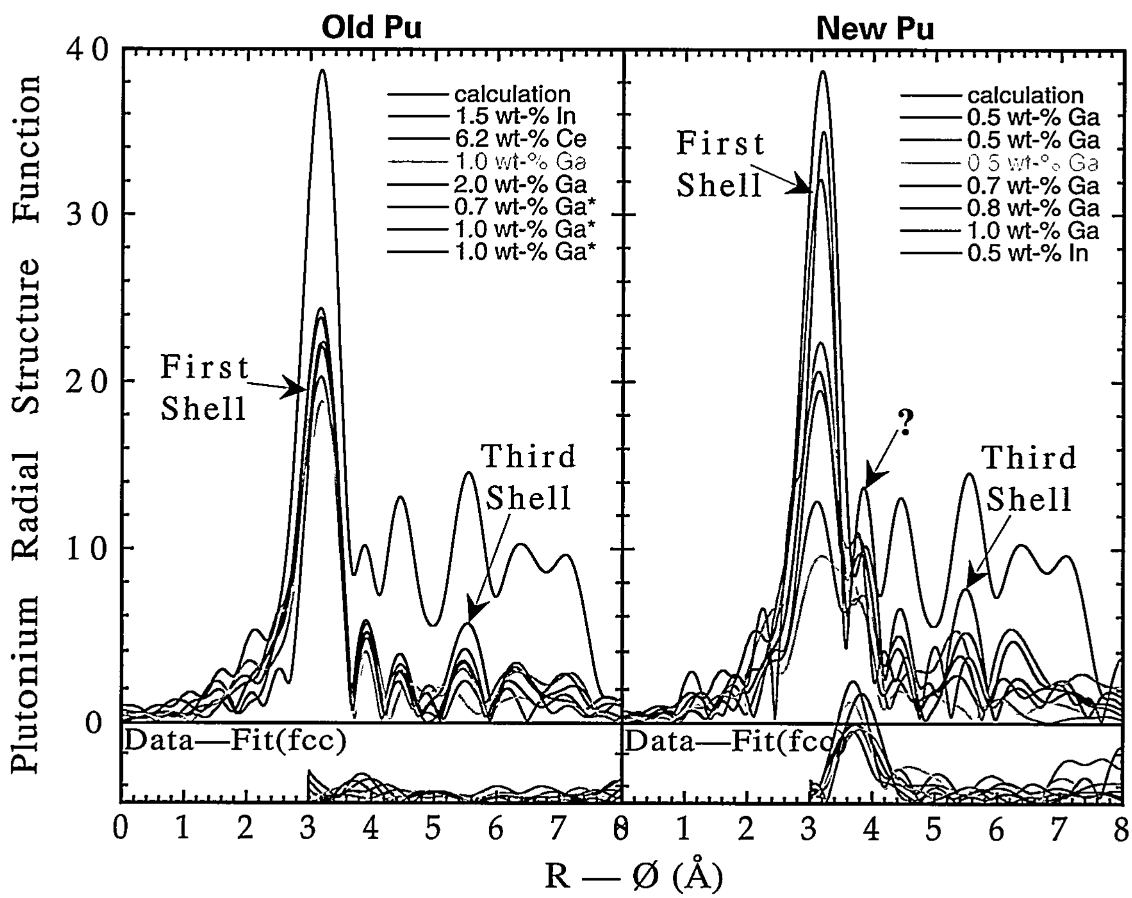


Figure LA13. *Comparison of XAFS data from new and old Pu.*

High Explosives (HE) and Initiation Systems

This focus area is intended to assess the effects of aging on the initiation, detonator/booster chain, and main-charge high-explosive components used in nuclear weapons systems in the enduring stockpile. The focus area includes characterization of the physical changes that may occur with aging (including physical, chemical, and mechanical, as well as safety and explosive performance aspects), development of nondestructive examination techniques that allow early and accurate detection of changes that may occur, and the development of models that allow projection of behavior into the future. The models will allow estimation of the lifetimes of existing components so that reasonable planning for potential refurbishment or remanufacturing can be made within the Stockpile Life Extension Program.

The work on initiation systems comprises the development of a new nondestructive examination technique used to assess aging of initiation cables. The detonator booster work consists of an evaluation of the performance aspects of old detonators that remain relevant to those in continuing service. A new test will evaluate divergence between the performance of "retired" detonators and those that will continue to be in the stockpile.

The effort surrounding main charges consists of assessments of the initiability (how promptly and where the detonation reaction begins), energy (how the high explosives move metal), and safety (the change of sensitivity with time). The work also includes necessary assessments of the high explosives as engineering materials.

These tasks were chosen to enhance our ability to predict high-explosive aging phenomena and remaining service lives. As appropriate, results of the work will be transferred to the routine surveillance testing program.

Deliverables

1. Partial discharge analysis test for initiation cables delivered to CSP.
2. Analytical and test-fire comparisons of new and aged PETN, LX-16, LX-13 and Ultrafine TATB explosives.
3. Models to predict future performance of PETN, LX-16, LX-13, and Ultrafine TATB.
4. Development and introduction into the CSP of a new divergence test.
5. Embedded magnetic impulse and velocity (MIV) comparisons of new and aged main-charge high explosives as well as transfer of the MIV test to the CSP.
6. Skid tests to evaluate aging effects on the safety of main-charge explosives.
7. Three-inch gun tests to evaluate effects of aging on the safety of main-charge explosives; introduction of this compact and analyzable test into practice in the CSP.
8. Characterization of aging effects on materials-related properties of PBX 9501, PBX 9502, XTX 8004, LX-04, and LX-17. Tests include molecular weight and mechanical properties such as strength and ductility. Models to predict future performance are being developed.
9. New nondestructive techniques to allow characterization of aging phenomena and the introduction of these technologies into the CSP.
10. Characterization of aging effects on the explosive performance of PBX 9501, PBX 9502, LX-04 and LX-17 main-charge high explosives as well as development of models to predict future behavior.

Pertinent Tasks

- **LL11** Enhanced Characterization of Stockpile-Aged Initiation Components
- **LL09** Detonator and Booster Reliability
- **LA07** Enhanced HE Surveillance
  - A. Initiability and Energy
  - B. Mechanical Properties
  - C. PBX 9501 Lifetime Prediction
  - D. Nondestructive Evaluation
- **LA25** Predictive Models for PBX 9501
- **LL06** Material Degradation Model Development
- **LL07** Enhanced Detection of Environmentally Driven Changes in Aged HE
- **LL08** Understanding Effects of Damage and Aging on Initiation and Performance in HE
- **LL10** Safety and Reliability of Stockpile-Aged Materials
- **LL14** In Situ Vibrational Spectroscopy

LL10 Safety and Reliability of Stockpile-Aged Materials

We need a compact, precise, and readily modeled measure of explosive sensitivity. The understanding of explosive aging on impact ignition and other hazards must improve as systems are being deployed longer than their initial estimated lifetimes. Since many scenarios cannot be tested, reliable reactive flow models based on data from well instrumented, reproducible experiments are necessary. We conducted compact and readily analyzable Steven tests on HMX-based explosives. Unaged materials were tested; tests on aged materials are planned.

The major advantages of the Steven test are its amenability to reactive flow modeling, its reproducibility, and its ability to produce unambiguous results. It yields just one main compressive pulse and is heavily instrumented. New experimental techniques of impact testing have been developed. We include several types of embedded pressure gauges to measure the interior pressure during reaction as well as microwave radar to measure the velocity of the projectile and expanding case during and after an explosion. For the first time in impact testing, these techniques are yielding quantitative measurements of the extent of high-explosive reaction. Reactive flow modeling of the Steven tests using standard Livermore hydrodynamic codes DYNA2D, DYNA3D, and ALE3D are now being done to determine the dominant physical mechanisms leading to HE ignition. The models are normalized to the available mechanical test data such as shear modulus, yield strength, and stress-strain curves at several strain rates and temperatures.

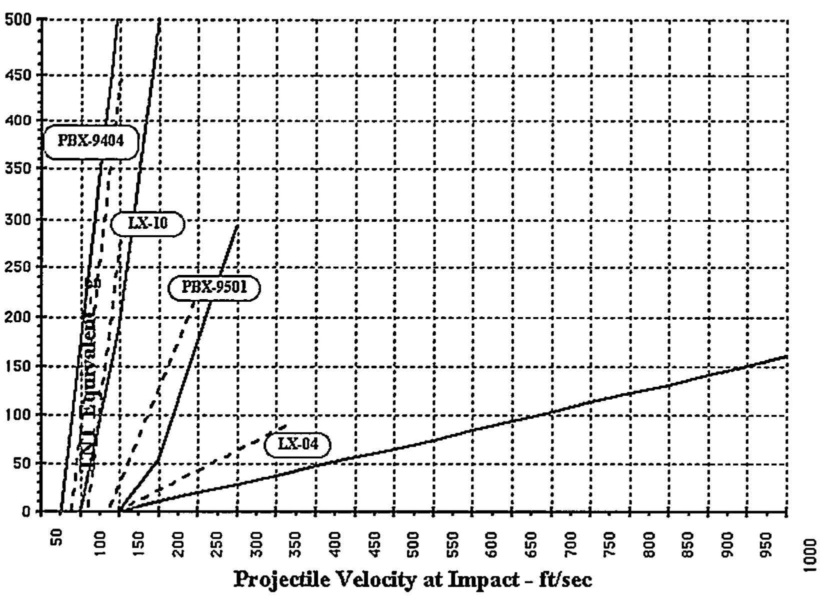


Figure LL10. *The relative order of decreasing sensitivity for unaged explosives is PBX-9404, CX-10, PBX-9501, and CX-04. The Steven tests provide unambiguous results compared to the scatter from Susan tests.*

The critical impact velocities for 60.1 mm diameter rounded steel projectiles in the Steven test were determined for new and aged HMX-based explosives. The violence of the resulting explosion was measured with external blast overpressure gauges. The relative order of decreasing sensitivity for new explosives was: PBX-9404, LX-10, PBX-9501, and LX-04 (Figure LL10.). This is the same order as observed in other impact tests, such as the Susan and skid tests. However, unlike the results from the other tests, there was no ambiguity in the Steven test results because there was a distinct critical velocity below which no reactions were observed. Above this critical velocity, the violence of explosion increased steadily with increasing impact velocity. The measured violence of reaction is greater in the Steven test than that observed at the same impact velocity in the Susan test. This is due to the greater confinement used in the Steven test, which allows the reaction to build up to higher levels of pressure before the confinement is breached, and the subsequent rarefaction waves decrease the reaction rates. We will begin to assess the effects of aging on violence of explosion in the coming year.

LL07 Enhanced Detection of Environment-Driven Changes in Aged HE

Using modern tools and techniques, some of which are described in detail below, we examined various chemical, physical, and mechanical signatures of the explosive LX-17 as it is affected by aging. Our findings:

- Stockpile aging up to 10 years appears to have a subtle but real effect on the binder molecular weight (MW). These changes were not observed in core surveillance because their range falls well within the data scatter of the existing measurement technique. Similar results have also been observed for LX-17 subjected to ~10 years accelerated aging via STS cycling.
- Using integrated experiments and irradiation dose modeling, we have determined that the equivalent of 60 years of pit irradiation will have negligible effects on the MW of the binder.
- Several observations have led us to conjecture that pit-induced heating in the W87 is sufficient to maintain the Kel-F binder in LX-17 above its glass transition temperature (Tg). This is an unexpected finding, which if true, might result in elevated rates for chemical and physical aging processes. This conjecture is based on (a) the analysis of trace chemicals absorbed in ambient-, stockpile- and accelerated-aged IHE, and (b) measurements of the percent crystallinity in the binder using high-sensitivity modulated differential scanning calorimetry (DSC).
- No deleterious effect has yet been observed from the absorption in HE of offgassing species from other organic components in the W87 warhead (see "Chemical Sensors," LL32, p. 34).
- Increasing binder crystallinity under prolonged exposure to temperatures above the binder Tg is consistent with the observation of an increase in dynamic stiffness at the upper end of the STS (Figure LL07).
- Aging appears to result in an increase in atomic pore volume within the binder and the TATB explosive. The results for the TATB are unexpected and will be confirmed and analyzed in future studies.
- Core surveillance data suggest that aging and cycling have no effect on tensile and compressive properties of LX-17-1. Aging and cycling on IHE core test units, however, reveal some changes. Future studies will focus on evaluation of these differing observations and their significance.

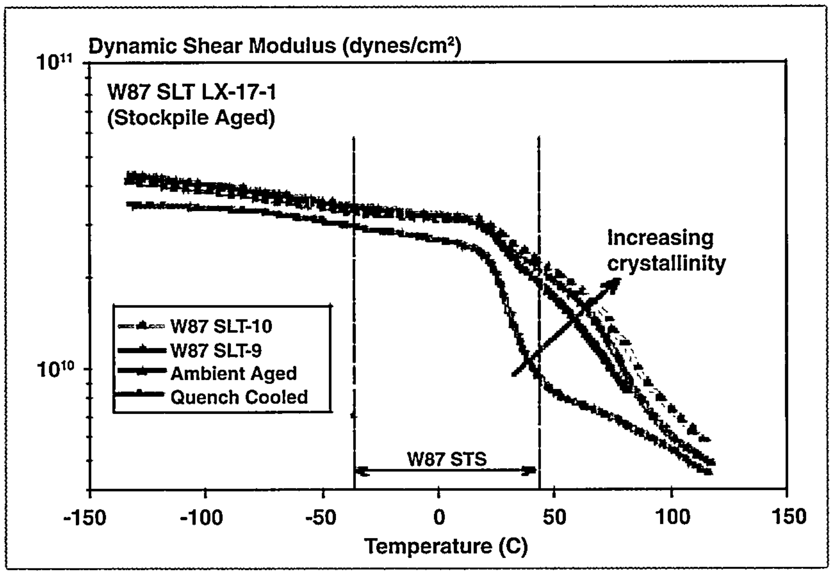


Figure LL07. *Slight increases in the dynamic stiffness of stockpile-aged LX-17-1 high explosive are consistent with small increases in binder crystallinity as measured via the highly sensitive technique of modulated DSC. Binder crystallinity should be able to increase only if stored for prolonged periods at temperatures above Tg of the binder. The lower curve shows LX-17-1 after quench cooling from 120 °C to remove all crystallinity in the binder. Stockpile ages: SLT-9 = 9.17 years; SLT-10 = 9.92 years. All LX-17-1 samples in this plot share a single Holston molding powder lot designation: 851-002.*

LA07 Spigot Gun Experiments

Nuclear weapons high explosive (HE) safety concerns focus primarily on inadvertent initiation of the main charge HE from mechanical or thermal insults. Examples of potential mechanical insults include the impact experienced by a weapon if it is dropped during handling or suffers a transportation-related accident. Under the most extreme of these conditions the potential exists to induce a high-explosive violent reaction. The HE formulations used in nuclear weapons were exhaustively characterized in terms of safety before introduction into the stockpile and found to satisfy safety goals. However, assessing the safety and sensitivity of stockpiled HE formulations as they age has not occurred traditionally because of the difficulty of designing and performing technically sound tests. Spigot gun experiments are a new method whereby the sensitivity of conventional HE formulations to low-amplitude mechanical insult may be assessed from stockpile samples.

The original spigot gun experiments were conceived at Lawrence Livermore National Laboratory.[1] Subsequently, Los Alamos National Laboratory modified the Livermore design for its "High Explosive Violent Reaction" test/modeling program.[2] The Enhanced Surveillance Program (ESP) work was built upon knowledge resident at Livermore and Los Alamos and modified the Los Alamos spigot gun experimental design to accommodate the size/shape constraints of HE samples obtained from stockpiled weapons. The ESP spigot gun target design uses a 5-in.-diameter by 0.5-in.-thick billet of PBX 9501 A 3-in. diameter, 2-kg mild steel projectile is fired at a range of velocities into the target assembly until a reaction threshold is determined. Because HE aging could cause changes in reaction violence as well as reaction thresholds, a sensitive new diagnostic test was needed. Thus, the ESP designed and manufactured a ballistic pendulum to hold the spigot gun target assembly. The displacement of the suspended pendulum is a function of the violence of the HE reaction, with the more violent reactions causing a greater pendulum displacement. Calibration of the pendulum is complete. Samples of PBX 9501 have been prepared and are being tested to establish baseline reaction thresholds. Examples of no reaction and violent reaction outcomes are presented in Figure LA07. Stockpile samples have been prepared from W76 main charges and will be tested late in FY97.

[1] S. K. Chidester, L. G. Green, C. G. Lee, "A Frictional Work Predictive Method for the Initiation of Solid High Explosives from Low Pressure Impacts," Lawrence Livermore National Laboratory report UCR JC-114186, July 1993.
[2] D. J. Idar, R. A. Lucht, R. Scammon, J. Straight, C. B. Skidmore, "PBX 9501 High Explosive Violent Response/Low Amplitude Insult Project: Phase 1," Los Alamos National Laboratory report LA-13164-MS, January 1997.

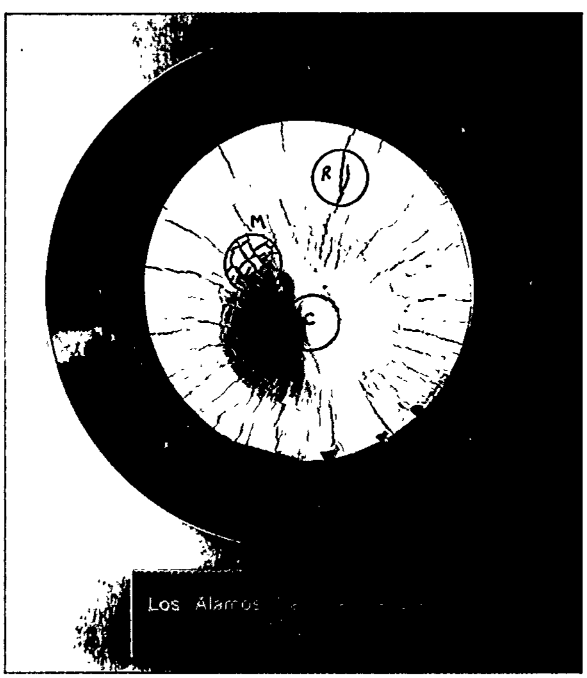


Figure LA07a. *No reaction: cracking of the HE sample but no charring or reaction.*

Figure LA07b. *HEVR: HE sample consumed, containment fractured.*

Understanding the Effects of Damage and Aging on Initiation and Performance of HE

It is important to know if the performance of a high explosive (HE) changes appreciably as a result of aging in weapons systems. How the detonation wave of an insensitive HE diverges from a localized initiation zone and propagates through the material is one measure of its viability. We compared divergence behavior in new and ten-year-old LX-17 and found somewhat better behavior in aged material. Baseline "divergence test" data were measured as part of original LX-17 powder lot qualification during the production period. This test used cylindrical samples cut from cylindrical, pressed billets of newly procured LX-17. When the cylinder was initiated with a flat initiation source (SE-1 detonator, PBX 9407 booster), the flatness of the detonation wave breakout pattern gave an indication of how reliably the wave propagated in that sample relative to others at different densities. It is recognized that IHE is such a relatively poorly performing explosive, the slow divergence or "corner turning" ability of these materials can be measured as a relative measure of performance reliability. An increase or decrease in the divergence angle with time could point to changes resulting from aging in key material properties.

With this in mind, the divergence of environmentally fatigued LX-17 was measured. The LX-17 came from an engineering test unit that had been run through thermal and vibration cycles to the stockpile-to-target-sequence extremes of the W87 system. The HE from such tests is normally discarded after disassembly. Specimens included divergence cylinders, "snowball," (a booster/detonator combination surrounded by a layer of main charge HE) tests, mechanical specimens, and analytical samples. Machining parts was coordinated with task LL09 ("Detonator and Booster Reliability," not included in this report), which requires booster-to-main-charge snowball samples from a number of sources. The divergence, snowball, and tensile samples where shipped to Pantex for testing under the supporting project there.

Divergence is measured as how far up the side of the cylinder the first breakout of the detonation wave occurs (Figure LL08). The ability of the detonation wave to diverge efficiently is known to be strongly sensitive to density. The test results showed that the divergence was better than expected compared to lot qualification test data. The breakout pattern was spatially more prompt, indicating a better "burn" in this aged material than was achieved with the same material ~10 years ago.

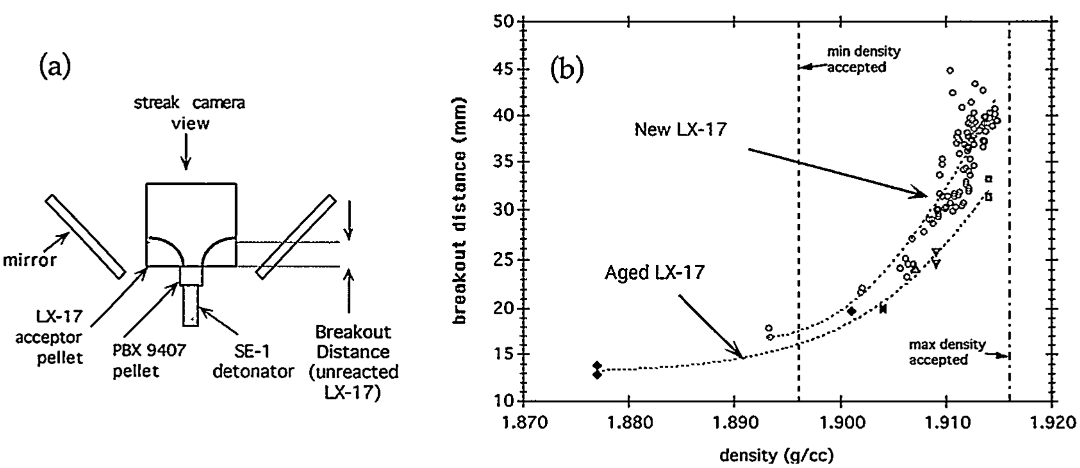


Figure LL08. *The aged LX-17 samples exhibit a shift in density-dependent divergence behavior. Detonation wave breakout is more prompt (shorter distance) than when the material was new. This effect is seen for pressed LX-17 samples either thermal-cycled or kept at ambient temperatures.*

Plotted as a function of cylinder density, these data follow a distinct trend with other aged LX-17 samples tested elsewhere. Specimens from pressed parts aging in different environmental conditions also show a better divergence or "corner turning" than anticipated. These samples included ambient-storage historical billets, thermal cycled parts, parts stored in environmentally controlled ambient surroundings, and stockpile laboratory test units (returns) that were destructively tested. The only recognized property they appear to have in common is that they are all 10 years older.

Mechanical property tensile tests were performed at Pantex, and torsion tests were carried out at Livermore. It is hoped that the results from these mechanical tests, being reviewed by LL07 ("Enhanced Detection of Environment-Driven Changes in Aged HE," page 14), will shed light on the unexpected change in divergent behavior of aged LX-17.

Organic Materials

This focus area addresses the state of technology for materials that are both nonenergetic and nonmetallic in character. The various elements that compose the Organic Focus Area of the ESP FY98-0 Program Plan provide for the development of baseline materials properties (where they do not exist) and characterization of stockpile-aged and accelerated-aged materials to support the development of predictive aging models. Our purpose is twofold: (1) to guarantee that the investment made by the Defense Program Office in materials technology is effectively utilized and focused on critical organic aging issues that impact Stockpile Stewardship and Management Program efforts; and (2) to ensure that necessary resources are devoted to what are perceived as the most critical organic aging concerns. The family of organic materials slated to remain in the enduring stockpile is quite broad in scope. However, we focus here on polymers and plastics. We limit our focus to a manageable number of polymers or polymer composites that dominate organic material concerns within the DOE.

We must gather more aging data and construct predictive models for the aging of critical organic applications and components. Furthermore, credible numerical models of weapon components in the stockpile-to-target sequence (STS) environment are needed, as are the data on the properties of supporting materials. Materials property information is needed for both aged and, in many cases, unaged states. In order to develop needed models and data, we must maintain the ability to perform state-of-the-art characterization needed to describe aging behaviors in terms that support predictive model development. Baseline mechanical properties for many of our organic materials are not currently available. However, full characterization of aging may not be required as not all material properties will be affected by aging. There are obvious physical signatures of chemical changes that remain incompletely characterized at this time. The NWC has already established baseline data for physiochemical properties for some of these materials, but the effects of aging are not always well characterized. To date, for those properties that are routinely monitored in the routine surveillance testing program, significant property changes have appeared in some of the non-HE organics where data are needed. We plan to characterize mechanical and physiochemical properties to "fill in the blanks." In FY98, we will begin to develop validated models needed to predict the effects of μ-scale changes, incurred as a result of aging, on organic materials. All of the new techniques, methodologies, and models developed here will be made available to the routine surveillance testing program for future evaluative purposes.

Deliverables

1. Finish parts retrieval from dismantled systems and expand parts acquisition to all extended stockpile systems.
2. Run stress-relaxation tests for M-9750, S-5445, and S-5455 cushion materials.
3. Quantify thermal dependence of stress relaxation in silicone foams and elastomers and compare to surveillance data.
4. Continue aging mechanism identification and characterization studies for additional prioritized materials.
5. Produce a report describing the mechanical behavior of PBX-type explosives and other weapon system organic materials and how they are affected by stockpile aging.
6. Apply nonlinear computational analysis to master kinetic equations in PBX 9501 systems and refine those master equations to include the new body of Estane aging data as it becomes available.
7. Incorporate both diffusion of small species and spatial inhomogeneity into the above code.
8. Produce a description of an accelerated-aging methodology for stockpile organics.
9. Perform quantum chemistry, molecular dynamics, and other more-detailed calculations to answer otherwise unanswerable questions about Estane chemistry.

Pertinent Tasks

- **LA06** Polymeric Materials Aging Program
- **LA24** Theory and Simulation of Polymer Aging
- **LL12** Aging Effects on Mechanical Properties
- **KC07** Foams, Cushions, and Shields for Stockpile Weapons

Theory and Simulation of Polymer Aging

A detailed master equation model of the kinetics of the aging of Estane 5703, the binder used in PBX 9501, is being developed. When complete, the model will be able to reliably predict the chemical composition and molecular weights of the Estane as functions of age over times longer than the current ages of any of the weapons. Its output will be used as input into other models being developed to calculate and predict the changes in the mechanical properties of the PBX as it ages.

Work thus far has shown that the number-average, weight-average, and z-average molecular weights (M_n, M_w, and M_z) can be predicted accurately for polymer reactions by solving a few moment equations rather than following each of the many thousands of polymer fragments in time.

The molecular weight of Estane first increases and then decreases with time implying that both crosslinking and degradation are occurring. The most important degradation mechanisms identified are (1) oxidative scission of the urethane links; (2) hydrolysis of the ester links; and (3) scission of bonds by free radicals produced by ionizing radiation and thermal degradation. In accelerated aging experiments any of these three mechanisms can be made to dominate. Our objective is to determine which dominates in stored weapons.

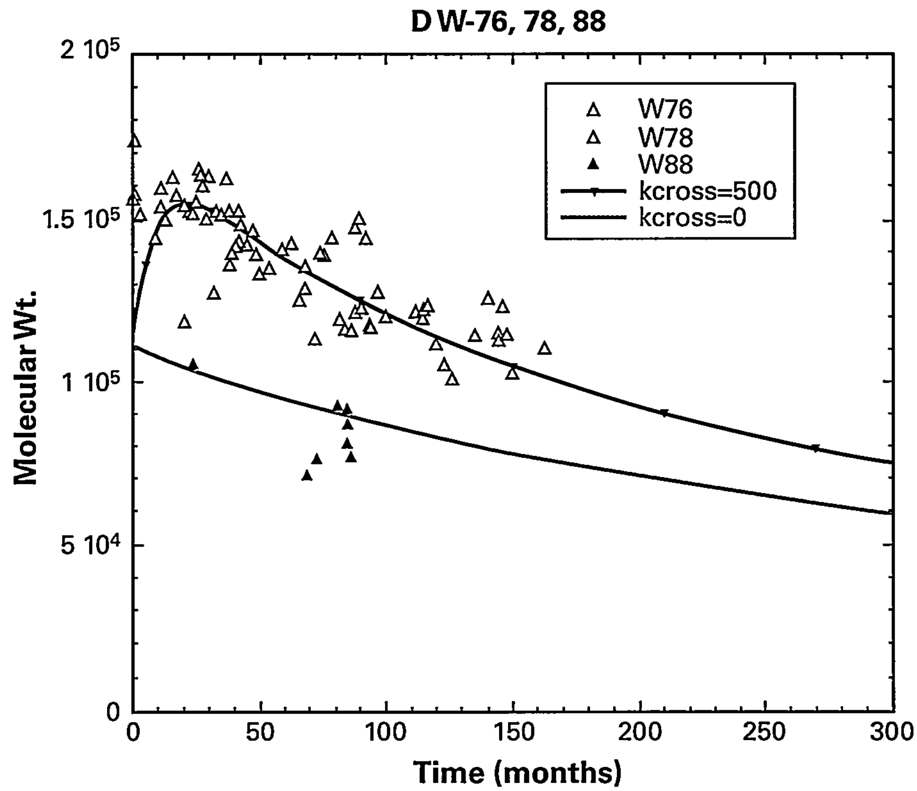


Figure LA24. *Estane molecular weight as a function of time. Model calculations are compared with surveillance data.*

The kinetics model contains all the reactions mentioned in the preceding paragraph; reactions of the nitroplasticizer; and the production, recombination, and scavenging of free radicals. At present, it has 28 species and 36 reactions. More reactions are being added as necessary. With this model it is very easy to fit the weapons data. As shown by Figure LA24, which compares the results of the model with actual Estane molecular weights, the surveillance data can be fit with only two nonzero rates (out of the 36).

However, as with all other present models, these predictions cannot be trusted beyond the experimental data until the model contains and is consistent with all known experiments on Estane. Such work is ongoing; it will take some time because many of the experiments on Estane are either contradictory or only qualitative. Experiments supporting this modeling are being performed at Pantex.

The first-ever measurements of the absolute molecular weights of Estane have been performed, identification of degradation products has begun, and aging experiments aimed at making large quantities of the degradation products are under way.

Polymeric Materials Aging Program

Aside from the limited-lifetime component, Polymers and HE may well be the limiting factors for the extension of the stockpile lifetime. There are approximately 60 types of polymeric materials and 200 polymeric components in the stockpile. The objective of the Polymeric Materials Aging Program (PMAP) is to identify and characterize aging mechanisms in polymeric materials in Los Alamos-designed weapons and to predict material properties in a weapon environment over an extended lifetime. Aging of high-priority materials is studied using a variety of analytical techniques to provide insight into changing chemical and mechanical properties. Models derived from these efforts are then tested by comparison with stockpile-aged parts and accelerated aging studies. Lifetimes are then estimated by extrapolating material properties through time to a predefined point of reduced function. The PMAP will provide constitutive evaluation, time-dependent mechanical and physical property models, and mass-transfer models to predict aging phenomena in enclosed systems. The program will exchange information with the Core Surveillance Program (CSP) to allow for improved surveillance testing where appropriate.

Efforts at Los Alamos over the past year were directed at assimilating data from historical aging studies and CSP tests, developing first-order material property models, and retrieving and testing stockpile-aged parts that are not tested under CSP. Historical aging studies conducted at Los Alamos and Allied Signal-Federal Manufacturing and Technology (AS-FM&T) over the past twenty-five years on S5370 and S5470 silicone foams were reviewed and used to generate first-order aging models for compression-set and load-deflection properties. Estane molecular weight data were assimilated and correlated with the axial strength of PBX 9501 to provide a first guess at the lifetime length of this material. These empirical models are being improved by incorporating findings from ongoing studies such as the stress-relaxation experiments being conducted on silicone materials. Thermal analysis equipment including a Rheometrics solids analyzer (Figure LA06), a differential scanning calorimeter, and a thermo-gravimetric analyzer were recently purchased to provide insight into viscoelastic and chemical processes that contribute to the relaxation of these materials. Testing is also planned for the more than 600 stockpile-aged polymeric parts retrieved from dismantled B61s and other systems disassembled under the CSP.

A network of support for PMAP activities has been established at Pantex, AS-FM&T, and Y-12. Stockpile-aged polymeric parts, including those from some of the oldest systems in the stockpile, have been retrieved from dismantled and disassembled systems at Pantex and Y-12. Extraction studies at AS-FM&T and Y-12 are being used to identify migratory chemicals and

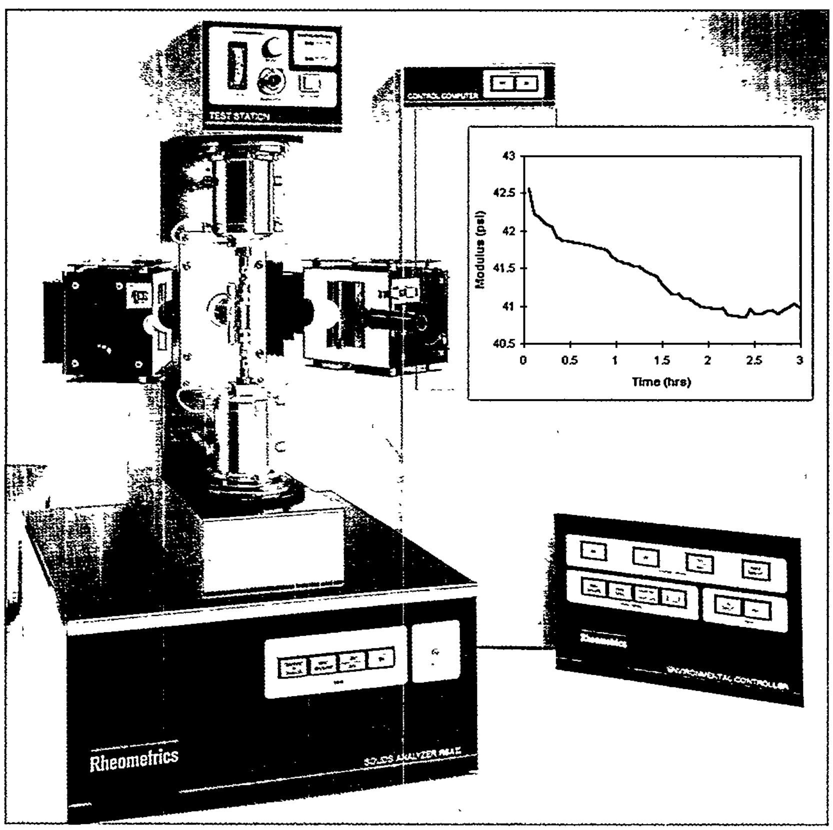


Figure LA06. *Rheometrics Solids Analyzer with superimposed stress relaxation data from S5370 foam.*

products of degradation. Mechanical testing equipment recently purchased by Y-12 will provide testing capabilities in a glove box environment and greatly simplify the task of testing stockpile-aged parts.

Collaboration of ESP efforts from around the NWC on aging of organic materials is largely achieved through information exchange and peer review at the Organic Materials Working Group meetings held approximately every two months. Irradiation studies are being planned on a variety of Los Alamos and Livermore materials with involvement of Los Alamos, Livermore, and Y-12 personnel.

Cellular Silicone Cushions

Cellular silicone cushions serve several functions. They fill gaps between components, compensate for manufacturing tolerances of adjacent components, and allow for thermal expansion. For the cushions to perform these jobs successfully, they are required to exert a specific compressive force at predetermined maximum and minimum gaps. Because the cellular silicone cushions must fill these gaps for the life of the weapon, the long-term stress behavior of the cushion under load is an ongoing concern.

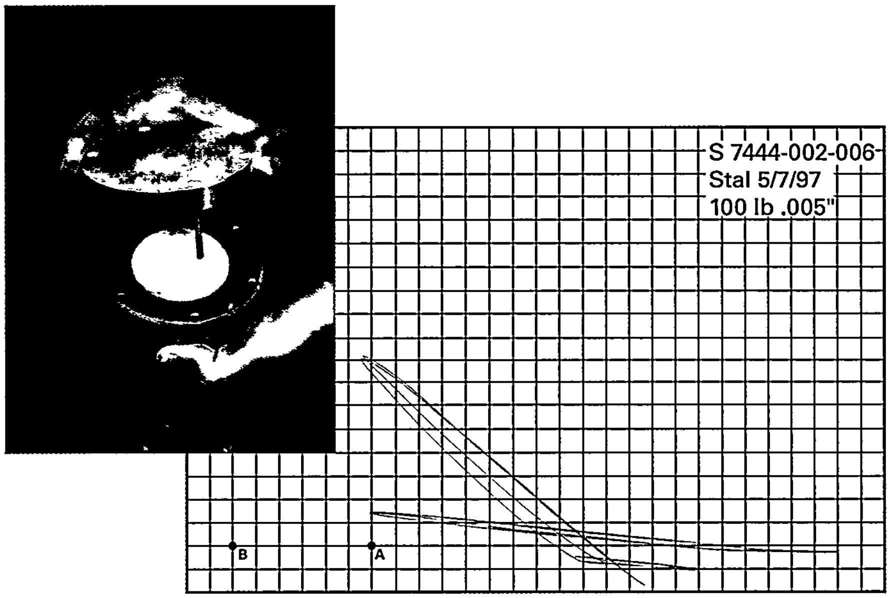


Figure KC07. *Cellular silicone aging fixture and representative stress relaxation test output.*

Allied Signal-Federal Manufacturing and Technology has conducted studies of various cushion materials in the past. At the end of those tests, the samples were left in the test configuration at specific compression and storage temperatures. While some ESP tasks require locating parts or components for evaluation, this task principally consists of resumption of testing of these existing aged parts, which are now up to 15 years old.

The following materials have been retested: M-9750 cellular silicone, used on the W87, and S-5445 and S-5455 cellular silicones. In addition, testing of S-5445 with fine urea is under way. This material is of interest because its smaller pore size will allow the molding of thinner cushions.

These samples were originally loaded into their aging fixtures, and the amount of load required to close the fixtures was recorded. At selected later time periods, the samples were retested to determine the amount of load required (less) to close the fixture. The difference was reported as a percentage of the original load value—percent load retention (PLR). A higher PLR indicates that the cushion is holding up well and that there is little compression set.

The data were reported in spreadsheet format, including original test results. The data will be sent electronically to experimenters at each NWC site responsible for these components. Contact Jim Schneider (jschneider@kcp.com).

The results of testing of M-9750 after approximately 4400, 4000, 3900 and 2100 days, aging respectively, indicate that the rate of PLR decrease has stabilized. Load retention decreased from 58% to 53% of original load between the 2100-day and 4400-day tests. The results for the S-5445, S-5455, and S-5445 with fine urea all show a continual decease in PLR but at a slightly higher rate. However, additional testing of the samples (cycling the load-bearing properties) will raise the PLR values. This was seen on the M-9750 samples described above and on previous aging studies. Results from additional testing will be reported as the data become available.

Dynamics

This focus area assesses the effects of aging on the integrated hydrodynamic performance of nuclear weapons components. The work consists of the development of new diagnostic techniques to better assess test results, precision characterization of explosive performance in high-explosive components, and improved utilization of hydrodynamic ("hydro") testing. The new diagnostic techniques and improved methods for hydrodynamic testing will be introduced into the routine surveillance testing program while the precision characterization will be used as part of the assessment of component lifetimes. Additionally, a disassembly/reassembly process will be developed using several units containing live high explosives (with mock pit and canned subassembly) units, assembled as closely as possible to war reserve requirements.

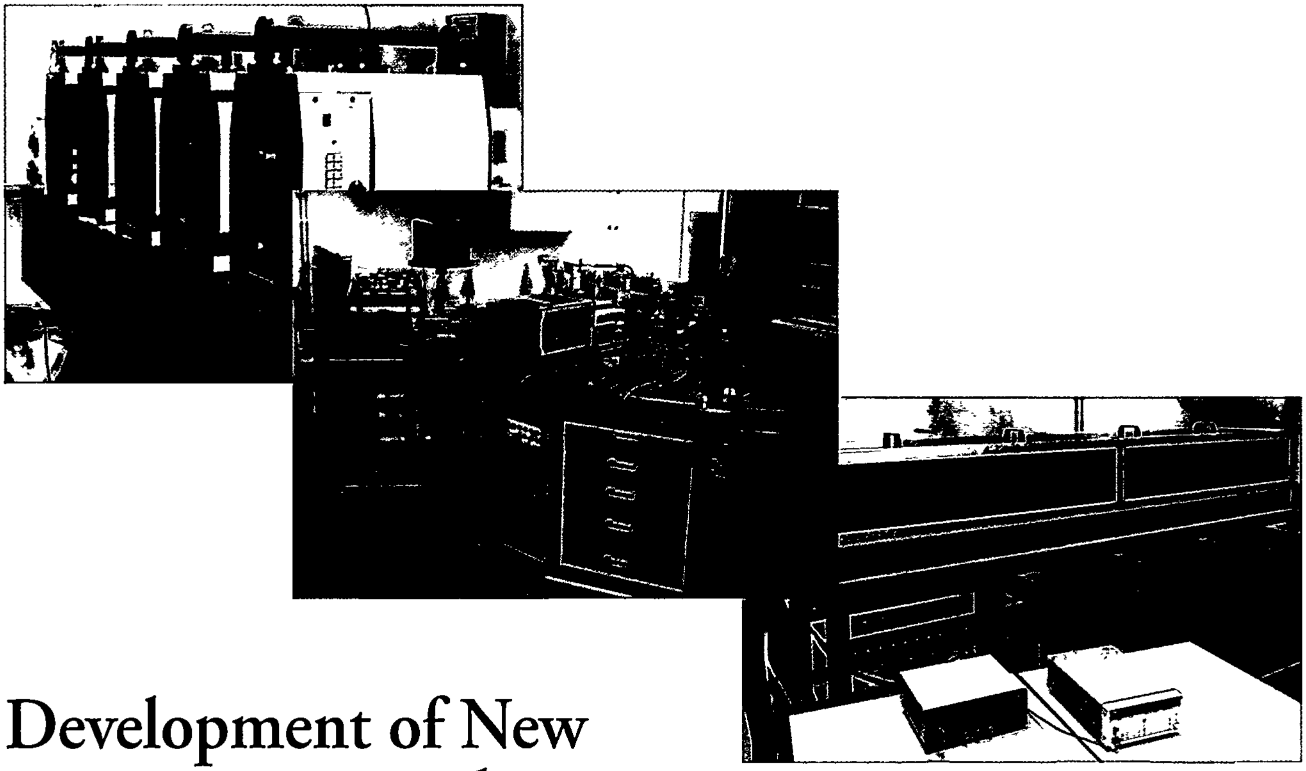
Work on new diagnostic techniques includes development of fiber-optic pin domes to better characterize the shock front velocity and shape, a multibeam Fabry Perot velocimetry to better characterize behavior of large high-explosive components, and picosecond microscopy to better characterize behavior of small components. These advanced diagnostics will be utilized in performance tests of both new and aged, small and large high-explosive components. Methods that allow hydrodynamic testing using the maximum possible number of aged components will be developed, demonstrated, and introduced into the routine surveillance testing program.

Deliverables

1. Fiber-optic pin domes.
2. Multibeam Fabry Perot velocimetry.
3. Picosecond microscopy.
4. Laser holography.
5. A screening test to assess aging effects rapidly and inexpensively on high-explosive performance, and introduction of this test into the Core Surveillance Program.
6. Bigplate and smallplate tests on new and aged main-charge high explosives.
7. Hydrodynamic tests using improved diagnostics for used, stockpile-aged components obtained during disassembly.

Pertinent Tasks

- KC02 Fiber-Optic Pin Domes for Hydro tests
- LL15 Development of New Hydro Measurement and Diagnostic Tools
- LL16 Aging Effects on Performance
- LL18 Changes in Shock Wave Profiles
- LL25 Development of Tests for Nontraditional Hydros
- LA01 Surveillance Hydro Tests
- LA02 Disassembly for Surveillance Hydros
- LL17 Laser-Assisted Sectioning



Development of New Measurement and Diagnostic Tools for Hydrodynamic Testing

Figure LL15. *Composite photograph showing the laser, analyzer table, and streak cameras under construction.*

In FY97 this task was primarily focused on completion of a 5-beam Fabry-Perot velocity diagnostic instrument. Velocimetry is an important aspect of high-explosive research. Many performance properties of HE that are important to the performance of a weapon (detonation wave velocity and pressure, detonation uniformity, etc.) can be determined using velocimetry. This diagnostic is an extremely important tool to validate the output of computer codes used to model the performance of high explosives.

As of July 1997 all major components had arrived and were installed. The instrumentation will be operational (except streak cameras) by the end of FY97. The laser source has been tested and integrated into the High-Explosives Applications Facility (HEAF). The analyzer is completed and tested, with the exception of the streak camera recorders. The system is 90% complete. Delays in converting funding to a fabrication account will result in completion of the Fabry-Perot system in November 1997.

A generic Fabry-Perot velocimeter consists of a laser source, a probe to illuminate a target of interest, an analyzer (Fabry-Perot interferometer) to convert the return signal to a usable form, and a recorder to retain the data. The laser source for the velocimeter in HEAF consists of a custom laser that produces a 100-mJ, 50-ms pulse at a 532-nm wavelength or a 65-mJ, 80-ms pulse at the same wavelength. This source is extremely bright and enables experiments to be conducted on diffuse targets. The laser is installed and was operated under HEAF facility control in early July. The probe technology was developed for a previous program. The laser feeds each probe through a fiber-optic cable that allows each probe to be independently targeted. Since all HE work in HEAF is done in contained firing tanks, the fiber optics must feed into the firing tanks at a gas-tight feed-through. The feed-through ports for the firing tanks to be used with the velocimeter in HEAF are completed. The return from the probe is fed to the analyzer table where the Fabry-Perot interferometer analyzes the wavelength of the Doppler-shifted return light, which is then recorded on the five streak cameras. The analyzer table is complete. The five streak cameras are in assembly but will not be completed during FY97 because of delays in converting funds for capital equipment purchases.

We purchased a new laser source and upgraded the laboratory facility for picosecond microscopy. The laser will be used to increase illumination levels, thereby allowing better temporal resolution.

Aging Effects on Performance

The objectives of the task are to 1) construct a set of explosive performance tests with simple geometries and 2) compare the performance of baseline explosive and a sample of aged explosive taken from stockpile storage. The explosives to be studied in the course of the program are LX-04 (85% HMX-15% Viton-A), ultrafine TATB, and LX-17 (92.5% TATB-7.5% kel-F).

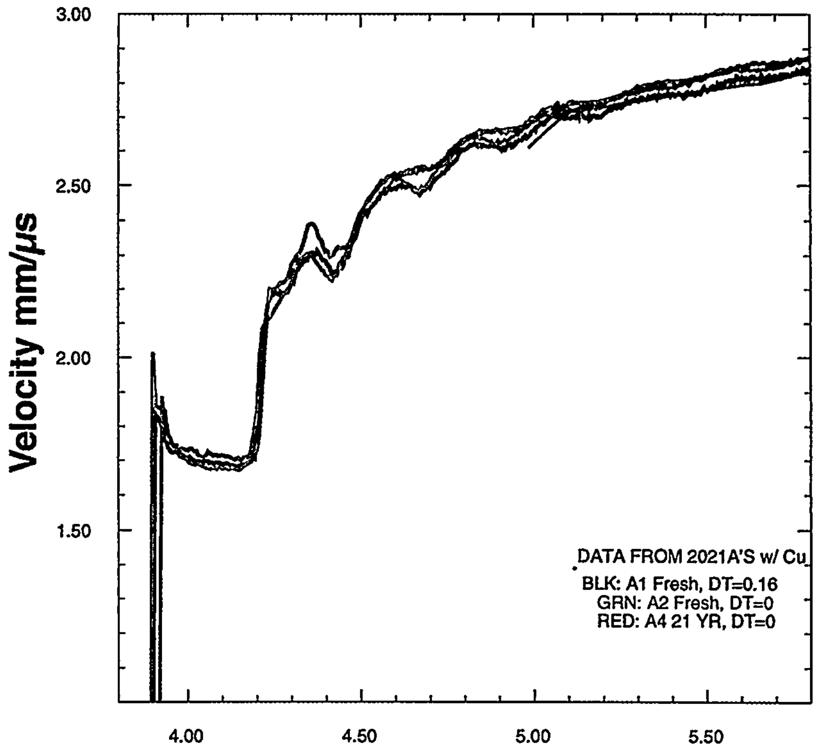


Figure LL16. *Bigplate LX-04/copper runs for baseline (light line) and 22-year-old aged (heavy line), showing no difference at the 0-mm, on-axis position.*

LX-04 "Bigplates" (≥ 8-in. diameter) Tests.
Two bigplates of baseline LX-04 (22 years old but pressed in 1997 before firing) and two of aged (same lot but pressed 22 years ago and machined this year to bigplate size), each with copper backing were fired. A baseline LX-04 shot with tantalum backing was also fired for a total of LX-04 bigplates. Design and fabrication of two baseline LX-17 bigplates has begun. The bigplate results are shown in Figure LL16 for the 0 mm on-axis position. The velocity of the free surface of the copper plate is shown. The curves have been lined up at the half-way point between the first and second jumps to remove slight timing differences. Within error, there is no difference between the baseline and aged velocities. The shot was also modeled using the analytical JWL (Jones Williams Lee) equation of state (EOS) and good agreement was obtained. Detonation-front curvatures of four shots were measured; no difference was seen between the two types of samples.

Cylinders.
Two copper cylinders each of baseline and aged LX-04 were fired, and the detonation velocity and detonation front curvature were measured. Detonation velocities of fresh 1960s LX-04 material were also compared, and measurable differences were not observed.

"Smallplate" (< 8-in. diameter) Tests.
Slapper-driven, ultrafine TATB disk shots have begun.

To date, bigplate and cylinder tests have been run on baseline and aged LX-04 with no change in explosive performance witnessed. An unexpected result and deliverable is the measurement of metal spall, as seen by the increase of the first velocity plateau. The spall is greater on axis than off.

Fiber-Optic Velocity Sensor

We are developing a diagnostic tool using Doppler-shifted light in optical fibers to measure the velocity and location-versus-time of high-velocity objects or shock fronts. The fiber-optic velocity sensor and recording system will augment current diagnostics used to assess the performance of explosively driven, imploding spherical systems in experiments conducted by Los Alamos and Livermore National Laboratories. This new sensor system will provide a continuous velocity and location measurement of a point on the imploding surface (instead of the location at one instant in time as given by the electrical pin currently used). The sensor does not rely on the finish or reflectivity of the imploding surface, so it can be used with materials known to provide poor light return under experimental conditions.

Two components of the system are under development:

- A newly designed velocity interferometer (VISAR) is being constructed. This design will make it possible to significantly reduce the size of a VISAR and make it more rugged and less expensive. It also improves safety of operation by containing the high-power laser beam within the optical fiber, reducing the possibility of accidental exposure.
- We are developing an optical fiber with a mechanical support that will return a repeatable Doppler-shifted light signal as it is crushed by an object or high pressure shock wave. This development requires the use of explosive-generated shock waves and explosively-driven flyer plates to crush the optical fibers in a realistic manner. Explosive experiments are currently being conducted at Los Alamos. Negotiations for use of Livermore explosive facilities are under way. Computer modeling is used to interpret results from experiments and provide direction for the experiments.

This task is a collaboration between Livermore, Los Alamos, and AS-FM&T. The fabrication facilities at AS-FM&T and the explosive experimental facilities and resources at Los Alamos are used to support the research and development of this sensor system.

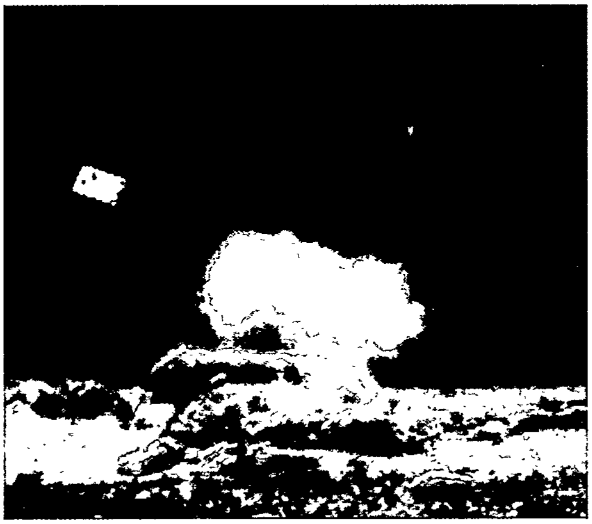


Figure KC02. *Fiber-optic velocity sensor explosive test.*

Diagnostics

This program element includes the development of a new suite of evaluation diagnostic methods and instruments that will aid in the early identification of aging problems in weapon system components and materials. New and more sensitive techniques are necessary to measure material and component properties and the effects of by-products (e.g., out-gassing of organic materials). The feasibility of real-time monitoring and self-aware system measurements are also being evaluated.

The motivation is to improve our ability to detect potential problems that may require refurbishment or related action. New techniques and methodologies that are developed will be made available to the Stockpile Surveillance Program for use in evaluation of surveillance return units.

This focus area is divided into the following program elements:

- Ultrasonics
- Tomography
- Mechanical Testing and Sensor Development
- In Situ Diagnostics
- Characterization and Analysis,
- Pit surface Analysis and Monitoring.

Ultrasonics

Advanced ultrasonic inspection methods for assessment of autoclave bonds as well as for other solid-state and adhesive bonds are being developed. These tools will provide much-improved capability to resolve interfacial features and therefore will be used within the routine surveillance testing program for early detection of potential defects such as corrosion and cracking. Different techniques are being developed for application to different types of weapon component geometries.

Deliverable

1. Ultrasonic inspection tool with better resolution than currently available.

Pertinent Tasks

- **LL19** Enhanced Ultrasonic characterization of Assemblies
- **LA19a** NDE Advanced Ultrasonics Tomography
- **SR05** Enhanced Inspection of Reservoir Girth Welds

Enhanced Ultrasonic Characterization of Assemblies

This project is developing ultrasonic technologies to assess the strength of bonds. Specifically, we are expanding our ultrasonic signal-processing and defect-characterization technology to interrogate bond lines and determine their quality. If bonds degrade with time, we will be able to track their aging and predict their remaining life.

For initial ultrasonic data acquisition, we designed, fabricated, and implemented a hand-held scanning device to evaluate pit bonds. We deliberately mistreated a major component to produce both unbonded and partially bonded areas. This ultrasonic image of a real part's bond line clearly displayed regions of differing bond quality. This nondestructive evaluation technology will assess the quality of autoclave bonds as well as other solid-state and adhesive bonds. This tool could be used for routine surveillance if costs and time to conduct the assessments are suitable. Alternatively, it could be used if destructive testing conducted as part of the Core Surveillance Program revealed a need to examine a larger number of components.

Livermore is working closely with the team members (Y-12, Allied Signal, and Savannah River Site) to implement ultrasonic data acquisition, bond classification, and display techniques. We designed a procedure to produce algorithms for classifying the quality of bonds. These algorithms extract information contained in the ultrasonic signal reflected by the bonded interface. The first step was identifying and writing signal-processing algorithms to process the acoustic data and to reject noise. Next we wrote feature extraction and feature selection software to recognize the pertinent characteristics of the ultrasonic waveforms to determine bond quality. We then developed the classification software based on statistical pattern recognition and probabilistic neural networks.

We began implementing classification techniques to correlate information contained in ultrasonic bond line signals with the quality of the bond. Figure LL19 shows this schematically. We fabricated a set of surrogate bond samples and implemented our signal-processing software to demonstrate feasibility.

Lastly, we are collaborating with another project to develop an automated, high-resolution ultrasonic scanning system for pit inspection. We will implement the advanced algorithms developed by the project on this computer-controlled system. The goal of this project is to implement procedures to determine ultrasonically the quality of bonds on weapon components. Ultimately, each of the partners will implement the technology developed by this project into their ultrasonic systems.

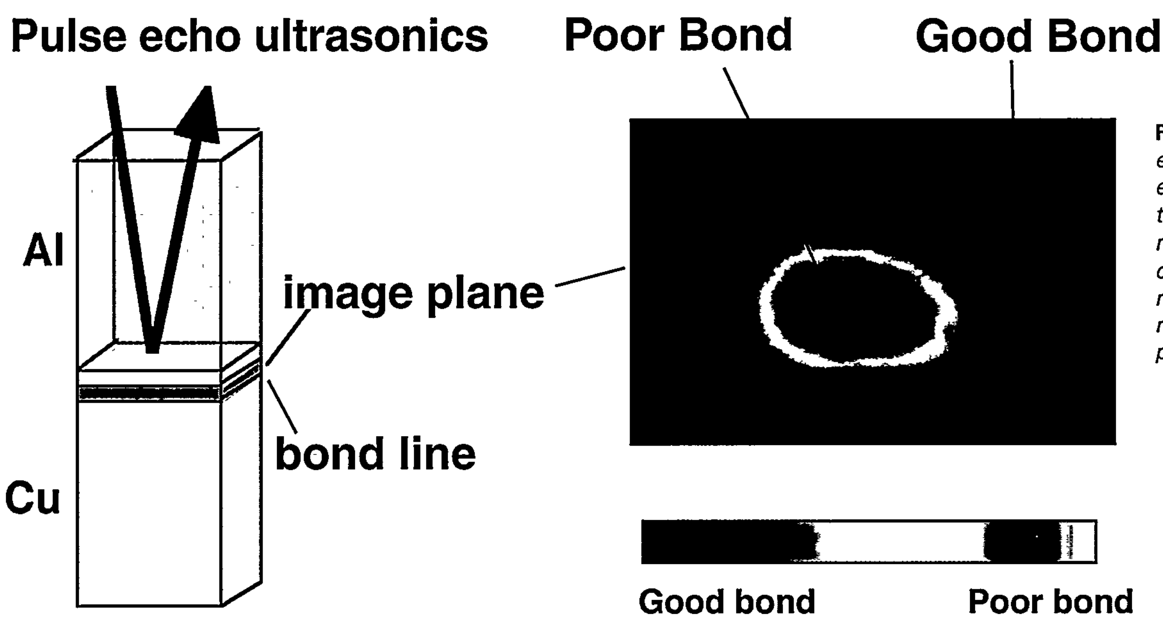


Figure LL19. *Pulse echo ultrasonics evaluate the bond line to image unbonded regions. The color-coded image on the right shows distinct regions of good and poor bonding.*

Tomography

Neutron radiography and high-definition x-ray tomography inspection tools are being developed for inspecting entire assemblies. When developed, these tools will provide much-improved capability to resolve fine features and therefore will be used within the routine surveillance testing program for early detection of potential defects such as corrosion, cracking etc. Specific techniques are being developed for application to component assemblies that have different geometries and materials.

Deliverables

1. Operational neutron imaging system capable of detecting millimeter-size voids or structural defects in low-Z materials.
2. High-definition x-ray tomography system with at least 1-mil resolution for detection of defects in partial and complete weapon assemblies.

Pertinent Tasks

- LL26 High-Resolution X-Ray Tomography
- LA19b Nondestructive Evaluation (NDE) Microtron Computed Tomography
- LA19c NDE Microtron Digital X-Ray Imaging
- LL24 Development of High-Energy Neutron Radiography

Development of High-Energy Neutron Radiography

This project is an effort to develop neutron radiography and tomography in the 10-MeV–15-MeV energy range for use as a nonintrusive inspection tool in stockpile-to-target sequence device engineering tests and stockpile surveillance applications. This could be used as a routine Core Surveillance Program (CSP) examination tool if costs and time required are suitable. Alternatively, it could be used if CSP destructive testing revealed the need to examine a larger number of components.

Our goal is to develop an operational neutron imaging system capable of detecting cubic-mm-scale voids and other structural defects in shielded low-Z materials within components (e.g. lithium salts, uranium, etc.). The imaging system that we have proposed will be relatively compact (suitable for use in existing nondestructive evaluation) facilities at DOE production and storage plants, particularly the Y-12 plant, and capable of capturing a full tomographic image of a nuclear device within the span of a few hours. It will consist of a high-yield neutron source operating in the 10 MeV–15 MeV energy range (a nominal output ≈ $10^{12}/4\pi$ n/sec/sr in the forward direction and an effective spot size ≈ 1 mm in diameter will be required), a low-mass rotation stage to support and manipulate the device under inspection (allowing for tomographic imaging), and the imaging detector itself. The imaging detector will be based on proven Nuclear Test Program technology and consists of a simple plastic scintillator viewed indirectly by one or more high-resolution (1024 x 1024 pixels), liquid-nitrogen-cooled, charge-coupled diode cameras.

We are currently building a prototype of the imaging detector and plan to test it by radiographing a suitable set of phantom targets at the Ohio University Accelerator Laboratory (OUAL) in Athens, Ohio, later in FY97. The OUAL features an accelerator-driven, high-energy neutron source and a shielded detector cave similar to that envisioned in a full-scale neutron imaging facility. We established the conceptual design for a high-yield, 10 MeV–15 MeV neutron source during FY97 working in collaboration with MIT (Massachusetts Institute of Technology). The source will consist of a small, commercially-available RFQ (radio-frequency quadrapole) linac running a 6-MeV–7-MeV deuterium beam into a windowless deuterium gas target. The major technical risk issues involved in the development of a high-yield neutron source such as this have already been addressed in a highly proprietary application; therefore, we believe we have an excellent chance of success in this area. Finally, during FY97 we have addressed a number of technical risk issues associated with exposing weaponized device assemblies to intense, fast-neutron beams. These issues include induced neutron activation of mechanical components and free hydrogen-isotope production within lithium salts (free hydrogen is highly corrosive). All of these issues have been addressed to the satisfaction of device designers and ESP engineering personnel. Assuming the success of these initial experiments, we will begin tomographic imaging tests in early FY98. A prototype neutron source will be developed in collaboration with MIT during FY98.

Imaging detector system based on proven technology

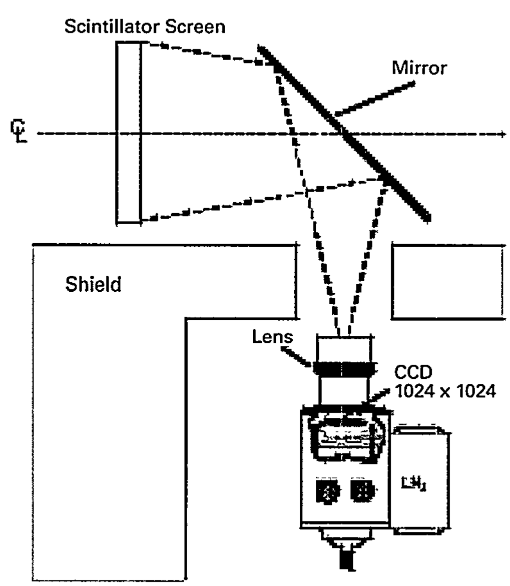


Figure LL24. *Schematic of high-energy neutron imaging detector and simulation of phantom target image.*

High-Resolution X-Ray Tomography

We are developing a high-definition, high-resolution x-ray tomographic capability for inspecting entire assemblies. The ultimate goal is to provide three-dimensional x-ray images with 0.001-in. spatial resolution or finer. An actual weapon component was imaged, and three-dimensional data sets were tomographically reconstructed. The resulting images reveal remarkable details that have never been previously observed by nondestructive methods. These images clearly illustrate the power and utility of the high-resolution, three-dimensional x-ray imaging technique. The images will be used to develop protocols for disassemblies.

The system will use a large-area, high-spatial-resolution detector to allow for the imaging of large objects in reasonable times. The image reconstruction will exploit the substantial *a priori* knowledge available for assemblies to produce the maximum resolution and contrast in the resulting three-dimensional image. This reconstruction results in reduction of image clutter and improves the signature and quantitative measurement of any potential anomalies. It also allows for a rapid, direct comparison to computer-aided design drawings of the assembly for prompt identification and localization of any detected anomalies.

The prototype x-ray tomography system is now operational and is being used to optimize the system's capabilities. This system uses an accelerator-based 9 MeV bremsstrahlung x-ray source, a rotating stage to hold the assembly being imaged, a glass scintillator plate to convert x-rays to visible light, and a lens/mirror coupled to a charge-coupled diode (CCD) as the detector.

The prototype system has been used in a series of parameter optimization experiments. Test objects were imaged and the results used to determine required system improvements. As a result of these tests the x-ray background shielding has been substantially improved, and the optical relay system between the scintillator and the CCD has been upgraded. The scintillator glass thickness was varied and optimized. The full-width half-maximum of the point spread function is 0.005 in. This spatial resolution allows features as small as a few thousandths of an inch to be detected and puts us close to our ultimate goal of 0.001-in. resolution.

A phantom object made from depleted uranium with features representing cracks, voids, pits, delaminations, and edge mismatches has been imaged. A novel image-reconstruction code based on algebraic reconstruction methods and use of *a priori* information has been utilized to produce three-dimensional images of the phantom object. The eccentric edge mismatch indicated is significantly enhanced by the use of *a priori* information of the object's structure compared to standard tomographic image reconstruction methods.

Mechanical Testing and Sensor Development

We are developing vibration and shock testing procedures and new promising techniques for detecting residual stress, corrosion, cracking, and other items of importance to diagnose damage and structural defects in weapon components.

Pertinent Tasks

- **LA28** Residual Stress Prediction
- **LA26** Analysis of High-Resolution Vibration for Damage ID
- **LA20** Low-level Vibration & Advanced Signal Analysis Techniques
- **LA21** Development of SQUID Microscope for Surveillance
- **SR02** Residual Stress Measurement of Reservoirs

Deliverables

1. Set of vibration and shock test procedures optimal for diagnosing structural defects.
2. "Toolbox" of signal analysis techniques for determining structural characteristics from test data.
3. Superconducting quantum interference device (SQUID) microscope to measure and map extremely weak magnetic fields associated with defects or corrosion.
4. Damage-detection system using high-resolution vibration analysis.
5. Extended state-of-the-art welding process models benchmarked against experimental data.
6. Laser-based technique for residual stress measurement in reservoirs.

Residual Stress Prediction

The Residual Stress Project has continued over the last year in collaboration with the Beryllium Testing Program at the Los Alamos Neutron Science Center (LANSCE). Efforts have been concentrated on making neutron powder diffraction measurements of strain distributions in test items of relevance to weapon system materials. These measurements are typically used to establish benchmarks and corresponding finite element calculations such as those being used during this same period by the "21-6-9 Study Group" of the Core Surveillance Program to investigate resistance-forge welds in 21-6-9 stainless steel structures.

Los Alamos had performed finite element calculations to model the welding configurations in question and had predicted high values for residual stress, but with significant variations between different weld configurations. A large number of assumptions are necessary in attempts to model such process operations (typically chosen to err on the side of overprediction in this study), and questions arose concerning the validity of the results. The Residual Stress Project thus initiated a collaboration with the 21-6-9 Study Group that resulted in the Savannah River Technology Center's providing resistance-forge weld specimens for neutron diffraction studies (both at LANSCE and at the National Institute for Standards and Technology) of the residual strains. These measurements compared favorably with the efforts to model the processes, indicating moderate overpredictions as expected and finding the same significant differences depending on the configurations used for the welds. These studies provided credence to the conclusions of the 21-6-9 Study Group. The figure gives examples of the calculations and measurements.

Figure LL28a

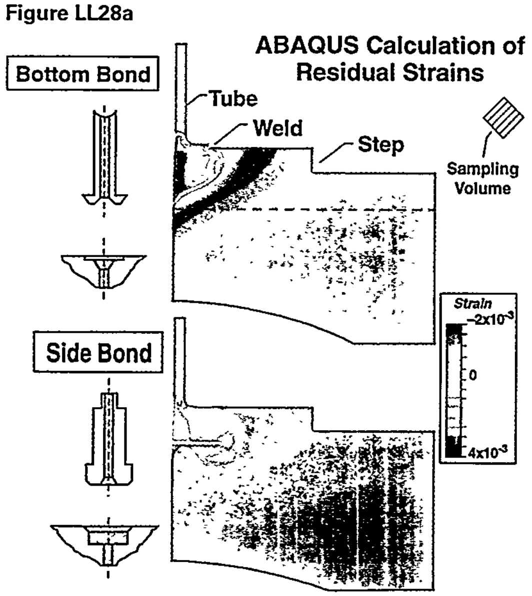


Figure LL28b

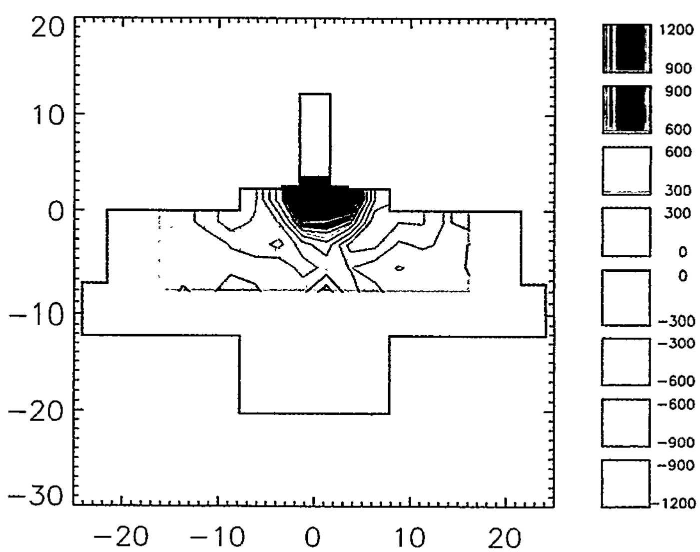


Figure LL28a. *Shown in Figure a are the hoop strains predicted by a finite element calculation used to model the results for a side-bonded weld.*

Figure LL28b. *Figure b shows a contour plot generated using results measured (on both sides of the nominal symmetry axis) by neutron powder diffraction techniques with a spatial resolution of approximately 2 mm.*

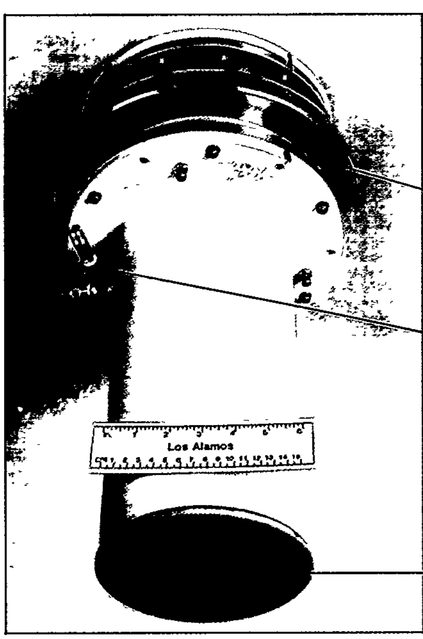
LA21 The SQUID Microscope

A nondestructive evaluation tool using advanced technology has been developed based on superconducting quantum interference devices, SQUIDS. The SQUID microscope will be able to detect anomalies nondestructively: submicron-size cracks, corrosion, inclusions, voids, and others in weapon components and subassemblies. The SQUID is uniquely suited for this application because of its ability to detect magnetic fields a billion times smaller than the earth's magnetic field.

A working prototype, shown here, has been designed and is undergoing testing with mock-up weapon components. Several technical hurdles have been overcome to date, including the following:

- The design of a nonmagnetic and nonconducting liquid nitrogen, which would minimize the impact of the dewar on the induction measurements planned for this project;
- Development of a thin-window and precision-variable SQUID mounting schemes to minimize SQUID-to-sample distance, minimize probability of window rupture, maintain SQUID temperature below superconducting critical temperature, and accurately and reproducibly position the SQUID relative to the window;
- Development of a nonmagnetic 2-D motion that would minimize the impact of the motor stage on induction measurements;
- Development of a background-rejection scheme that eliminates the magnetic background at the SQUID sensor. The rejection attained for this project is the highest yet reported anywhere and is near the theoretical limit determined by circuit delays; and
- Design of a high-frequency (~10Mhz) feedback circuit for SQUID control and data acquisition. This development improves existing state-of-the-art by an order of magnitude and directly impacts both SQUID frequency response and dynamic range.

This project resulted from a close collaboration of scientists at Los Alamos, Allied Signal-Federal Manufacturing and Technology, and Savannah River. The enhanced surveillance SQUID microscope team is partnering with a wide range of programs, including National Institutes of Health and Office of Health and Environmental Research, which are developing SQUID sensors for medical applications. Additionally, Los Alamos is continuing basic SQUID research at the Superconducting Technology Center through Laboratory-Directed Research and Development programs.



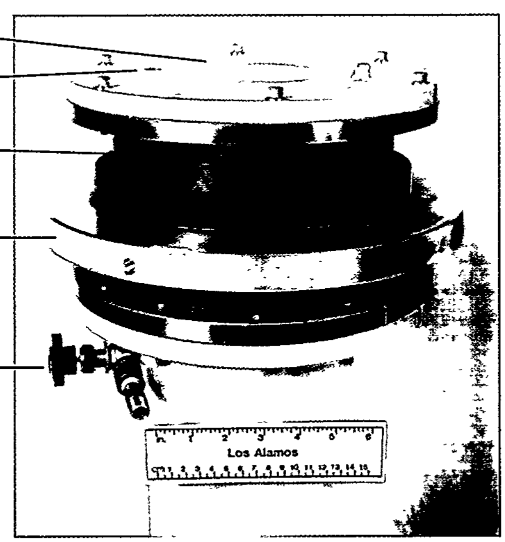


Figure LA21. *The first prototype of the vacuum dewar for the SQUID.*

In Situ Diagnostics

A strategy for in situ monitoring of early signatures of aging in weapon systems will be developed. We will include the evaluation of the engineering feasibility of these strategies, determine their practicality, define appropriate detection concepts, develop needed technology, and evaluate prototypes to support an implementation decision for in situ monitoring. The extent of application will depend on the degree of success in developing strategies for engineering feasibility that allow installation and continuous monitoring approaches that do not affect component performance. If development is successful, these tools will be adopted by the Core Surveillance Program for continuous monitoring of weapons behavior.

Deliverables

1. Suite of fiber-optic sensors for in situ monitoring of core stacks and stockpile weapon systems.
2. Optochemical sensors with neural networks that measure, record, and broadcast in real time the presence of various chemicals.
3. Miniature, nonintrusive, real-time gas monitor, which can be incorporated in rebuilds or surgically implanted in existing stockpile units.

Pertinent Tasks

- LL32 Sensors and Detectors
- SN13 System Studies for In Situ Monitoring
- KC06 On-Board Chemical Sensors for Stockpile
- OR15 Real-time Gas Monitor
- KC01 Fiber-Net HE Decomposition Product Sensor
- OR18 Laser Penetration Sampling

Fiber-Optic Hydrogen Sensor

A new hydrogen gas sensor is being developed using a novel Bragg grating in an optical fiber. The Bragg grating hydrogen sensor is incorporated with a stable fiber-optic laser. The quantity of hydrogen present is measured by the wavelength change of the fiber-optic sensor. The miniature fiber-optic sensor provides a minimally invasive, simple, mechanical technique for measuring hydrogen gas. This sensor is being developed for potential in situ measurements of high-explosive degradation products in weapon environments.

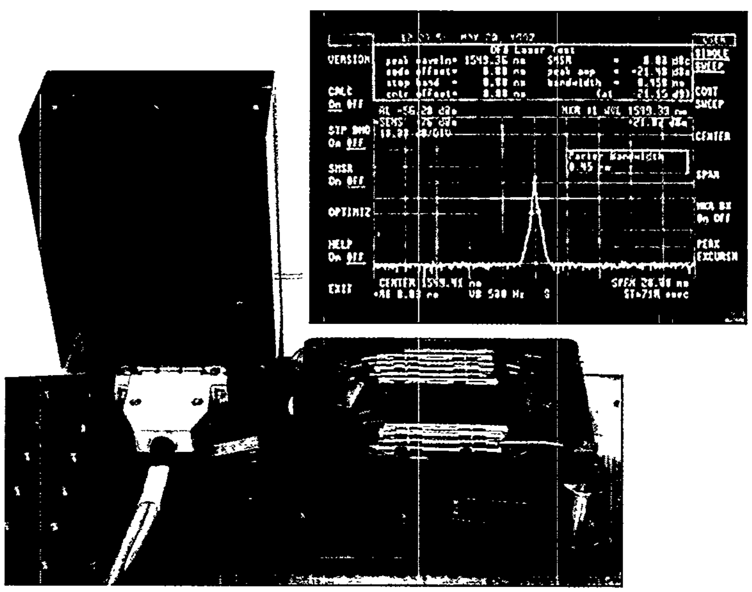


Figure KC01. *Prototype Bragg grating hydrogen sensor showing system output.*

A working prototype, shown here, incorporates a 1550-nanometer fiber-optic laser with a 980-nanometer pump. The Bragg grating hydrogen sensor is at the other end of a several-meters-long, fiber-optic pigtail. Several technologies were being developed during FY97 for this task, including the following:

- Construction of a totally stable fiber-optic laser,
- Electroless plating of palladium,
- Thermal compensation of the sensor system, and
- Calibration curve determination and electronic integration.

This task resulted from an enhanced surveillance effort to survey the field of fiber-optic gas sensors suitable for high-explosive degradation measurements. The unique characteristics of this sensor are its subminiature size, its simplistic mechanical operation, and system reproducibility under realistic weapon environments. Manufacturing processes for the Bragg grating hydrogen sensor will be the subject of FY98 development efforts.

Laser Penetration and Rewelding for Gas Sampling

The feasibility of using a laser to drill a hole to sample the gas in a weapon's secondary and subsequently resealing the hole has been demonstrated using a Nd:YAG laser on stainless steel flat plate. Correlations discovered in another ESP task between the presence of a specific gas and the aging profile of a unit highlight the need for a nondestructive surveillance diagnostic capability. Such a technique would provide the ability to sample gas within a unit and, depending on the results of the analysis, reseal the unit for its return to the stockpile. A conceptual flowsheet of a secondary gas-sampling process for a secondary is shown in Figure OR18.

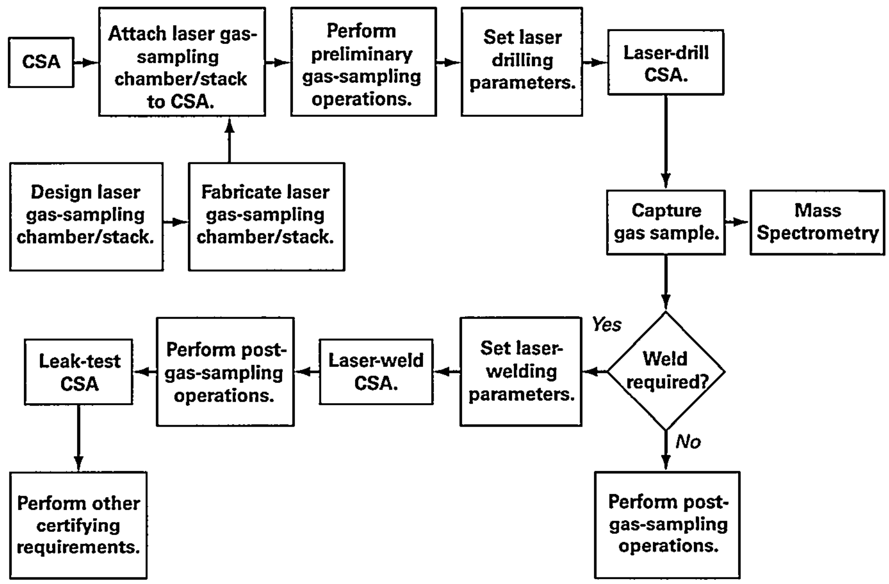


Figure OR18. *Flowsheet of the gas-sampling process.*

We are pursuing characterization of the drilling and welding parameters and techniques required for this effort using a pulsed Nd:YAG laser and a Nd:Glass laser. Initial work was done on the Nd:YAG laser since it is located in the development area and is not needed for production work. Holes and welds were made in 0.010- and 0.030-in. thick stainless steel flat plate by varying laser drilling and welding parameters such as focusing lens, focus distance, laser pulse width, and laser power output. Laser-drilled holes were successfully sealed in both the 0.010- and 0.030-in. plates by simply defocusing the laser beam.

Evaluation of the same technique has begun using the Nd:Glass laser, which is routinely used in the Core Surveillance Program (CSP) to penetrate an assembly and take a gas sample. Resealing the drilled hole has not been necessary since the units sampled are disassembled. To date there has been no success in resealing using the Nd:Glass laser by defocusing it, but only a limited number of samples have been evaluated. Further evaluation is in progress.

A risk assessment was performed to determine the optimum location for sampling. Factors such as wall thickness, accessibility, material variations, and the likelihood of contamination were considered. Based on this assessment, the probability of success would be highest at the resistance crimp weld in the outgassing tube or through the outgassing tube adjacent to the crimp weld. As a result, a new laser gas-sampling chamber/stack has been designed and will be fabricated in the near future. The new stack will provide a window for the laser beam and a port from which to obtain the gas sample.

In addition to the flat plate described above, stainless steel tubes have been received for evaluation. Material from disassembled units has also been received so that process feasibility can be demonstrated.

Laser drilling and welding parameters and techniques have been developed at Los Alamos and the Pantex Plant. Procedures, drawings, photos, etc. have been obtained. The techniques developed cannot be applied directly at Y-12, but where appropriate, they will be adapted to support this development.

Chemical Sensors

We are developing sensor technology for inclusion in cans that contain combinations of weapon materials called "core stacks" and other specified surveillance schemes. If all questions pertaining to the inclusion of sensors can be answered positively in the future, it may be possible to include them in stockpiled weapons. A test facility and optoelectronics systems were completed. A well coordinated sensor development team involving Livermore, Allied Signal-Federal Manufacturing and Technology (AS-FM&T), and Savannah River Technology Center (SRTC) has been formed. Different sensing schemes using minimally intrusive optical fibers are being explored: reflectivity (for hydrogen) and fluorescence quenching/enhancement (for other molecules). Both techniques rely upon the selective interaction between sensor coatings (placed on the ends of the optical fibers or on lenses) and gas phase molecules of interest.

Different materials for hydrogen sensors are being explored including palladium (a proven technology) and another proprietary material, which has shown very promising results, at SRTC/AS-FM&T. New prototype sensors for ammonia and nitrogen dioxide (two possible HE decomposition products) have been demonstrated at Livermore (see data in Figure LL13 for nitrogen dioxide). Sensitivity in the 10s of parts per million has been demonstrated for the ammonia sensor.

Immediate plans for this project are to implement the hydrogen sensors in the core stack tests at Y-12. These sensors will be able to provide real-time data and can be used to compare design options and obtain kinetic data in compatibility tests. Sensor development is being coordinated with solid-phase microextraction analysis of dead volume gases, as described in LL13 ("Solid-Phase Microextraction," page 37), which can provide guidance in sensor development by identifying additional chemical targets.

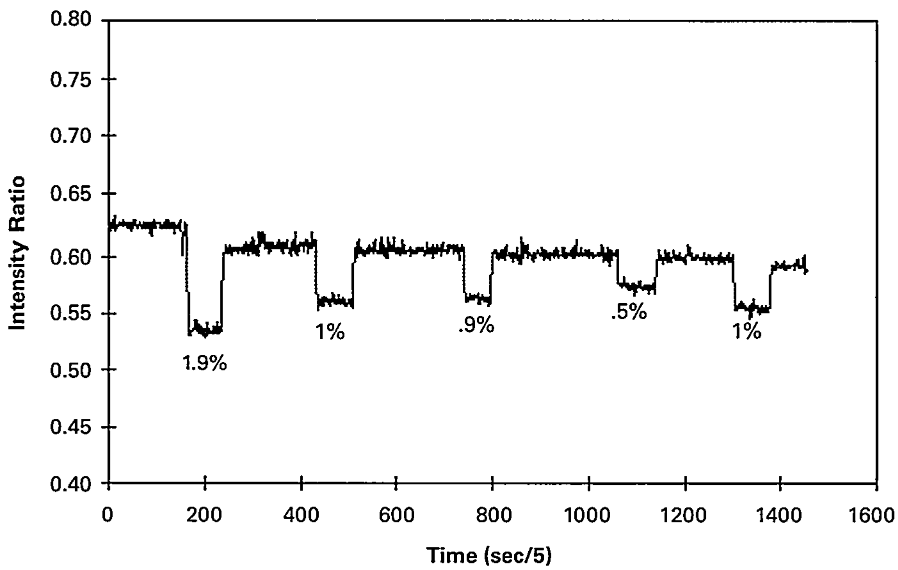


Figure LL32. *Response of a prototype fiber optic sensor for nitrogen dioxide to varying concentrations of nitrogen dioxide in nitrogen. The sensor was fabricated by dip-coating the end of an optical fiber into silica sol-gel solution containing a fluorescent ruthenium compound, then allowing the coating to dry, forming a rigid coating on the end of the fiber.*

KC06 On-Board Chemical Sensors for Stockpile Weapons

Prototype fiber-optic sensors for temperature and hydrogen have been developed and tested. These sensors can provide a time log of temperature and hydrogen concentration within a weapon in real time. These data will allow improved assessment of potential corrosion occurring within the weapon midcase as well as assisting in the modeling of component- and material-aging behavior.

Working prototypes have been built and will soon be put into testing with materials compatibility test samples. Several technical advances have been accomplished, including the following:

- A fiber-optic temperature sensor utilizing zinc selenide has been designed, built, and tested satisfactorily.
- Fiber-optic hydrogen sensors using palladium films have been built and are being tested. Various coatings have been developed to prevent fouling of the film while allowing the penetration of hydrogen.
- A new fiber-optic hydrogen sensor is in development using thin binary layers of yttrium and palladium. Initial results with this new concept indicate improved sensitivity and better stability compared to the palladium-only sensor.
- Deposition techniques to make the Y/Pd sensors have been successfully developed. Furthermore, the extension of this concept to other binary films such as Er/Pd, Ce/Pd, and Nd/Pd is now in progress.

These accomplishments have been the result of a very close working relationship between AS-FM&T and Savannah River Technology Center.

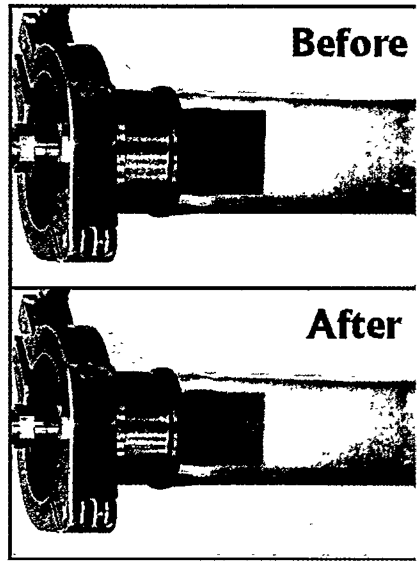


Figure KC06. *Coated Y/Pd film hydrogen sensor showing change when 3% hydrogen is introduced.*

Characterization and Analysis

Characterization tools and analytical methodologies for assessing aging, degradation, and corrosion effects in weapon systems and components will be developed. These tools will be used during the course of ESP to develop understanding of aging and degradation, and some tools may be adopted within the Core Surveillance Program (CSP) for periodic monitoring of weapons behavior. This set of tools, if successfully developed and implemented into the CSP, will allow identification of early signs of degradation of organic components and potential effects not only on the organics themselves but also on metallic components. The suite of tools can be applied to nondestructive examination of the warhead space of stockpiled weapons during periodic surveillance. If laser drilling and sealing are successful, the tools may also be similarly applied to stockpile canned subassemblies. If not, then they will likely be applied to destructive examination only.

Deliverables

1. Solid-phase microextraction sampling method for analysis of organic compound decomposition and resultant effects in weapon headspace atmospheres and CSAs.
2. Integrated suite of sensors to detect chemical signatures for nonnuclear components in a weapon's internal atmosphere.
3. Fiber-optic-coupled laser for analyzing high-explosive decomposition products.
4. Prototype infrared gas analyzer to supplement residual gas analyzer.
5. Laser drilling and welding process for sampling and CSAs.

Pertinent Tasks

- LL13 Solid-Phase Microextraction
- OR04 Infrared Gas Analysis
- OR05 Infrared Surface Analysis
- OR09 Hydrogen Balanced Methods
- OR10 Gas Transport
- KC03 Fiber-Laser Flurometer for Materials Analysis
- SR02 Laser-Based Residual Stress Measurements
- SN14 Chemometric Analysis of Weapon Internal Atmospheres

Laser-Based Residual Stress Measurements

A revolutionary technique to measure residual stresses has been demonstrated experimentally. When fully developed, this technique will be able to determine residual stresses in weapon components. Knowledge of residual stresses is particularly important in long-life welded structures that may be subjected to thermal and mechanical shock and fatigue. This is the only practical residual stress technique that can measure engineering stresses without material removal. Therefore, it has the potential to monitor weapon components in service.

A conceptual drawing of the device is shown in Figure SR02. The device contains a laser speckle-pattern interferometer that is capable of measuring surface strains in three directions and a charge-coupled diode (CCD) camera that captures the interferograms. The interferometer and CCD camera are controlled by a IBM-compatible personal computer. The measurement is performed by first collecting an image of the area of interest with the CCD camera while the interferometer's diode lasers illuminate the spot. A small region in the center of the illuminated spot is then heated with a small carbon dioxide laser. For materials of interest the low maximum temperatures (~200 °C) do not harm the material. Heat is efficiently coupled into the surface by applying a dab of liquid, temperature-indicating paint, which melts at a predetermined temperature and absorbs infrared light very efficiently. Once the spot has cooled, another image is collected by the CCD camera. The two images are combined to form a fringe pattern that measures the surface strain-relief that has resulted from this annealing process. The residual stress is then related to the measured strain. Accomplishments to date include the following:

- We have demonstrated this technique in the laboratory for 304L stainless steel for both uniaxial strain and biaxial strain. Experiments were performed and compared with finite element simulations with excellent agreement.
- An easy-to-use semiempirical model has been developed that can be used to calculate the residual stresses for 304L stainless steel. This model is being expanded to include 21-6-9 stainless steel.
- Experimental capability has been established at the Savannah River Technology Center (SRTC). All previous experimental work was carried out at the University of Alabama in Huntsville under the direction of SRTC. The basic idea, however, is an SRTC invention, and a patent has been granted with a second patent pending. This new capability at SRTC will allow us to investigate parts and materials of interest.
- An x-ray diffractometer has been specified and ordered. The diffractometer will be used to establish benchmark results from this laser new technique.

This project also involves collaboration with Los Alamos National Laboratory. Los Alamos is working on a material removal technique for measuring residual stresses know as "slot cutting." This technique is especially useful for objects whose stress in uniaxial but varies in magnitude through the thickness of the material. The SRTC is participating in a round-robin experiment with Los Alamos. Most of the finite element simulations have been performed at SRTC, but we are working with the University of South Carolina in Columbia to do simulations as well.

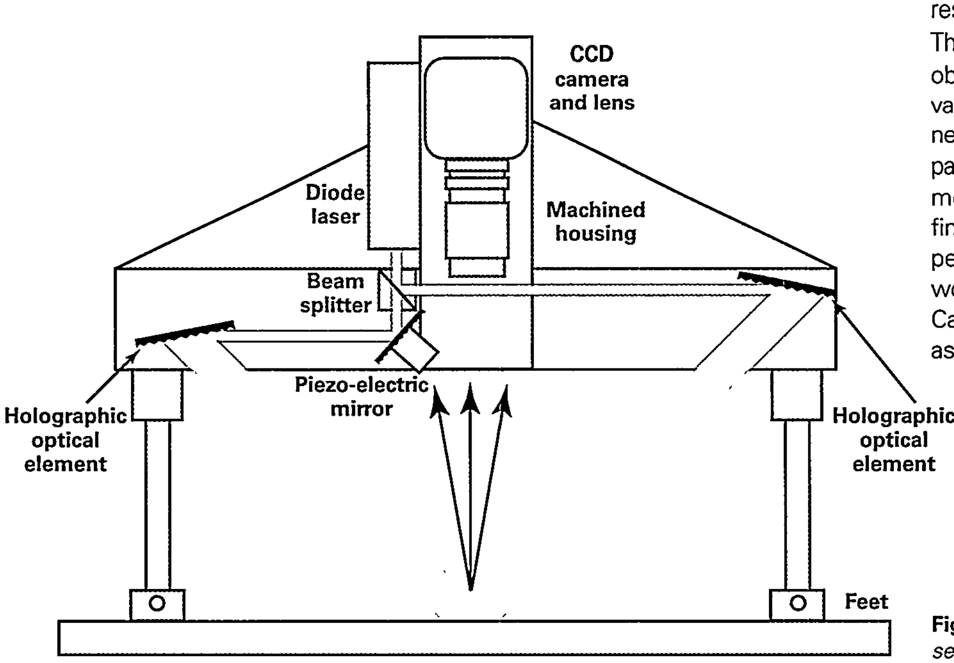


Figure SR02. *Schematic of residual stress sensor showing one measurement axis.*

Solid-Phase Microextraction

We are using a technique called "solid-phase microextraction" (SPME) to analyze the weapons' headspace gases to help determine how aging and environment may affect the stability of weapons components. The purpose of this work is to extend our knowledge of gas-phase chemicals that may indicate material degradation, corrosion of any metal components, or the integrity of other organic materials, which then indicate compatibility concerns in the systems. Many of the organic materials used in modern systems are amorphous, semicrystalline polymers that are generally thought to be stable because of characteristically small diffusion coefficients (10^{-11} to 10^{-5} cm^2/sec). However, we have determined that these materials do outgas at significant levels. The chemicals that are outgassed may include processing aids, synthesis precursors, reaction byproducts and degradation products. In addition to detection of changes in materials resulting from environment or aging, microextraction can detect the residues left over from the assembly or rebuilding of system components. With microextraction, a microsized fiber that is coated with a solid phase adsorbant (Figure LL13) is exposed to the weapon headspace gas to collect any chemical species. This approach is a nonintrusive sampling method where the outgassed chemicals are preconcentrated onto the fiber without collecting any bulk gas. Analysis of the microextraction fiber is performed by gas chromatography/mass spectrometry (GC/MS), where the fiber assembly is directly injected and then thermally desorbed in a heated GC injector port.

Thus far we have characterized the W87 and B83 weapons and have analyzed high explosives from two W87 weapons, finding nothing we would characterize as deleterious. Many of the additional compounds conceivably absorbed in the W87 high explosive may be traced to the usage of other materials. As an example, significant levels of toluene arise from its use as a solvent in the synthesis of the high explosive. Analysis of the data so far leads us to believe that the outgassing and absorption processes observed on the core samples would not have significant effects on other materials in the near term because the outgassed species identified to date are nonreactive. The second and most recent application of this technique involves the analysis of different weapon systems. We compared microextraction at two sampling locations. As expected, higher signals were achieved by sampling closer to the weapon. Work is in progress to move the fiber even closer, to within 10 cm of the weapon purge valve, permitting direct sampling of the weapon headspace by eliminating losses on the gas line walls, thus resulting in more accurate quantification. For the first system studied, we found differences in relative concentrations between the actual weapon and those from the material standards, indicating differences in outgassing and absorbing events. Our next step is to complete the initial survey of Livermore systems and associated materials that make up the enduring stockpile, including Livermore-designed canned subassemblies.

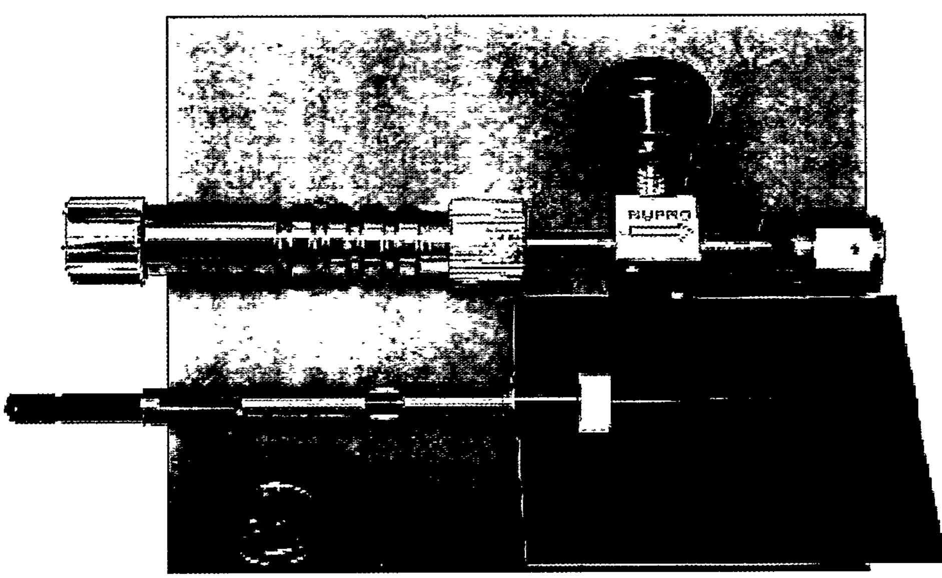


Figure LL13. *Air-tight microextractor assembly indicating relative size of coated micro-extraction fiber and assembly as compared with a quarter (fiber is <400 μm).*

The Surface Inspection Machine/Infrared (SIMIR)

We have developed a nondestructive surface inspection tool that interrogates a millimeter-sized spot on surfaces by diffusely scattering infrared light off the surface and then determines from it an infrared spectrum. Since this spectrum contains explicit chemical information about the surface and is highly sensitive, the SIMIR (see Figure OR05a) is an excellent tool for evaluating surface contaminants on surfaces being returned from stockpiled units. The identification of the presence and quantity of contaminants provides information critical for accessing effects of aging in that unit. When coupled with positioning devices to manipulate the specimen at the sampling port of the SIMIR, each spectrum occupies a pixel in a map that can display the inspected surface as 3-D surface maps (see Figure OR05b). These pixels may be interpreted by a host of spectrometric or chemometric methods. The spectra represent the highest-quality spectral data, and the images represent the present limit for such image analysis.

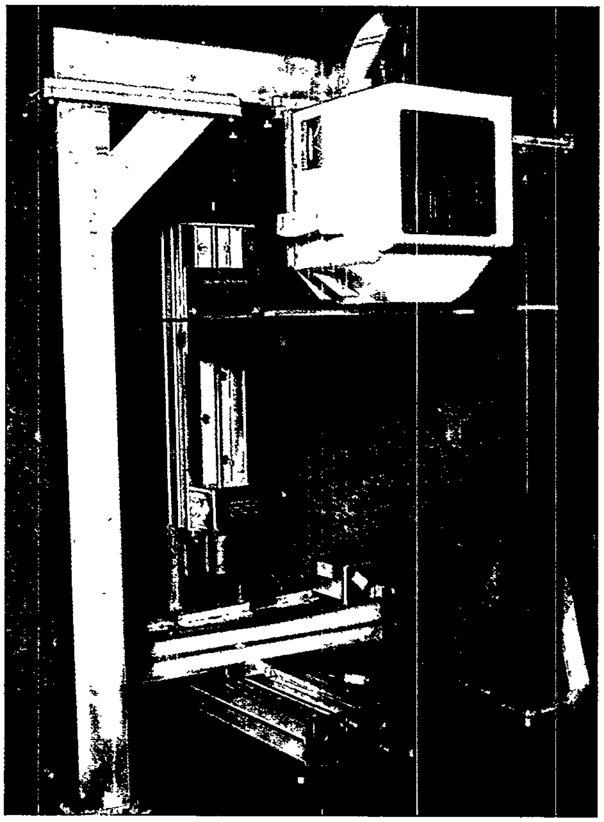


Figure OR05a. *The SIMIR in the flat-surface mapping configuration.*

Accomplishments in FY97 are as follows:

- Lockheed Marietta Energy Systems and Livermore have acquired SIMIRs and are developing facilities for inspecting LiH for LiOH. They are also developing methods for generating chemically specific surface maps.
- Pantex and Los Alamos have also acquired SIMIRs for the inspection of organic contamination, such as adhesives, plasticizers, and explosives on metal components. Los Alamos, in collaboration with Surface Optics Corporation, has further developed the SIMIR so that interior surfaces can be analyzed through glove box walls.
- This technology will be transferred to the Core Surveillance Program in FY98.

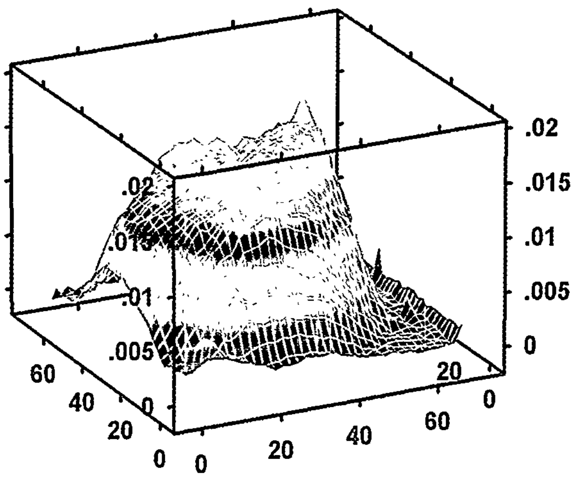


Figure OR05b. *Silicone stain ~200 nm thick resulting from 0.7 mg of light silicone oil spreading over a 70-mm by 70-mm sandblasted gold coupon.*

KC03 Fiber-Optic Laser Fluorometer

A fiber-optically coupled ultrviolet (UV) laser fluorometer system is being evaluated. This field-portable analytical tool will utilize a fiber-optic endoscope to perform real-time chemical analysis inside enclosed volumes in an assembled weapon. The fiber-optic laser fluorometer system will extract all spectral signatures for which it has been "trained" and notify the operator if there is an unknown or out-of-limit spectral signature. The nonintrusive inspection system will be able to identify known chemicals and detect the presence of unknown contaminants.

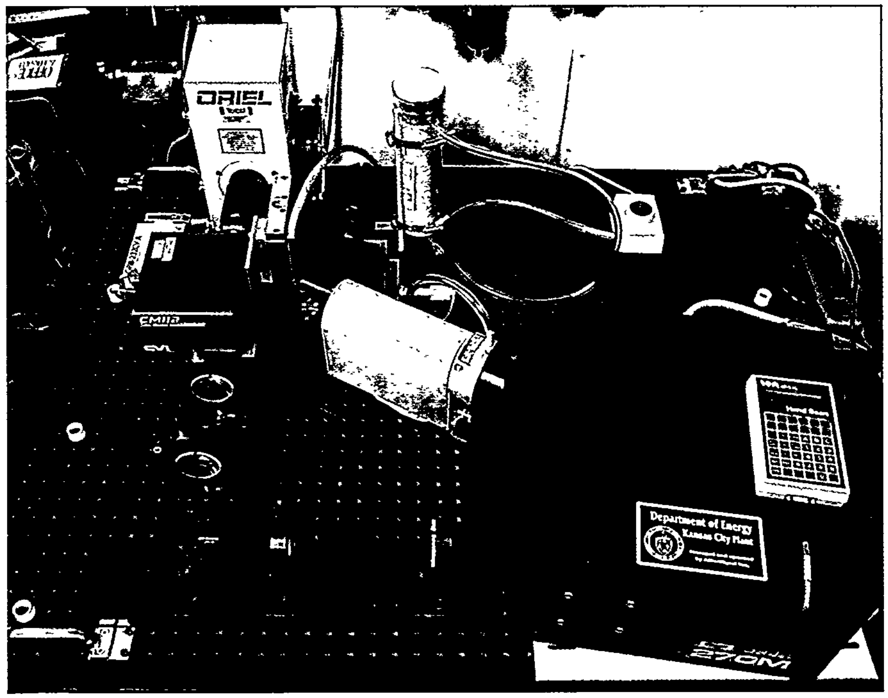


Figure KC03. *Breadboard fiber-optic laser fluorometer system.*

A dedicated laboratory breadboard system, shown in figure KC03, has been procured and assembled and is undergoing evaluation. The following accomplishments are highlights of work performed in FY97:

- A bench-top UV-tunable laser was procured and set up. The laser will be integrated into the breadboard system to determine laser requirements and critical system parameters.
- Enhanced pattern recognition software was developed that can identify chemical compositions from fluorescence spectra. A fluorescence spectra library of pure and binary chemical solutions was used to "train" the neural networks. The test results demonstrated the capability of the pattern recognition software to be "trained" on fluorescence spectra and to subsequently identify constituents of the liquid chemical samples.
- Development of a unique software tool for signal processing, feature extraction, and pattern recognition was begun early in 1997. This software, the Feature Extraction Toolbox, will provide an integrated data processing, data evaluation, and data visualization environment for pattern-recognition applications. This toolbox can generally be used for any application where signal or image data must be analyzed and interpreted. A prototype of this toolbox will be available by October 1997.
- A conceptual design review was held at AS-FM&T in collaboration with Livermore to define the interface requirements of the multipurpose endoscope. This review outlined the mechanical and optical interface criteria for each analytical tool and determined the optical requirements for each system. The optical paths were defined and documented. This documentation will become the compatibility interface definition that will be used by each of the facilities.

AS-FM&T, Livermore, and Savannah River are working closely to develop multiuse applications for the endoscope. This close collaboration has resulted in the development of a suite of analytical tools that will utilize the same endoscope to collect data. This suite of tools includes imagery analysis, chemical analysis, and surface-roughness measurements. These tools can be applied to evaluation of primaries, reservoirs, and other enclosed volumes.

Chemometric Analysis of Weapon Internal Atmospheres

Chemometric tools are being developed to extract time/age information from the gas analysis of weapon internal atmospheres. The fundamental hypothesis underlying this project is the idea that the integrated time/ temperature history that a weapon has experienced will be encoded in the composition of its internal atmosphere. Through application of the advanced modeling and pattern-recognition techniques that chemometrics supply, the diagnostic sensitivity of surveillance measurements made on a weapon's internal atmosphere will be enhanced. This, in turn, will enable a weapon's history to be deciphered yielding information of increased value to the surveillance program. The combination of surveillance measurements with the chemometric models should be able to provide a general indicator of an individual weapon's "state of health."

The ultimate goal of this multiyear project is to develop a set of tools to integrate into the core surveillance program that will enable potential age-related problems to be identified with high sensitivity at the earliest possible moment. Nonintrusive gas sampling coupled with chemometric data analysis is much easier and less costly than disassembly and inspection for obtaining age-related information.

An example of extracting age-related information from gas analysis is shown in the figure. These data were taken directly from the existing surveillance database and illustrate the idea of combining several types of data into a single, coherent, predictive model. Data from approximately 135 units of a particular weapon type was used to create the model. The prediction panel shows age predictions for about 50 more units. It is important to note that no data from any of these 50 units were used in the model development. In other words, the model is truly predictive. The foregoing analysis shows the feasibility of obtaining meaningful age-related information from the gas composition of a weapon's internal atmosphere. In addition, it demonstrates the power of detection to identify units that fall outside of the normal variation band ("outliers"). One unit, for example, was found to have an atmosphere that was essentially air, which is different than the expected atmosphere. Other accomplishments include the following:

- The process for obtaining digital gas chromatography data from weapon internal atmospheres has been completed.
- Initial chemometric algorithms have been selected and applied to over 100 chromatograms from core surveillance gas samples. Results include identification of outliers from the "normal" population.
- Essential components for the toolbox including data preprocessing tools are being assembled and tested, e.g., filters, baseline correction, chromatogram alignment.
- Duplicate sample analyses have begun with 20 duplicate samples analyzed at both Pantex (using gas chromatography) and Sandia (using GC/mass spectrometry).
- The core surveillance gas analysis data are also being examined to see if there is a correlation between the organic chromatograms and the inorganic gas analyses.

This work is a collaborative effort between Pantex and Sandia/New Mexico.

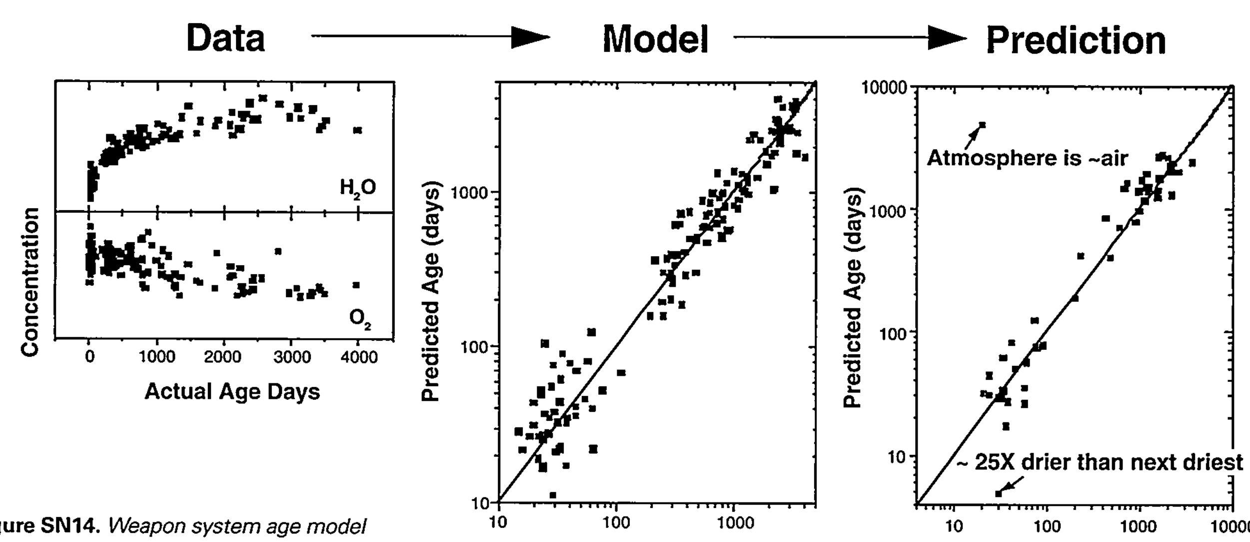


Figure SN14. *Weapon system age model based on O_2 and H_2O surveillance data.*

Pit Surface Analysis and Monitoring

New methods for evaluating the chemistry of external and internal pits surfaces are being developed to provide data on the potential reactions of other chemical species in the weapon environment. Once successful, the tasks (listed to the right) will result in tools that can be used by the routine surveillance testing program for periodic examination of pit surface conditions. Two types of tools are being developed; the first will allow detailed chemical analysis of exterior surfaces, and the second will allow detailed analyses of special surfaces. The latter are being very carefully evaluated to assure that damage will not be introduced as a result of the examination.

Deliverables

1. Instrumentation for direct examination of the external surface chemistry of the clad metal on pits.
2. Expanded monitoring program to provide real-time aging data on pits stored at Pantex.

Pertinent Tasks

- **LL05** Endoscopic Imaging and Optical Coherence Tomography
- **PX01** Pit Surface Characterization
- **PX02** Enhanced Monitoring with Remote Sensing
- **PX06** Reaction of Plasticizers with Clad Metal Surfaces

PX01/06 Pit Surface Characterization

Pit Surface Characterization (PSC) will make use of new surveillance technologies that will quantify and document the condition of pits based on an understanding of their surface chemistry. The nondestructive examination of pit surfaces with instrumentation especially configured to characterize the surfaces of entire pits is new; it does not exist in the Nuclear Weapons Complex, nor indeed, anywhere else. The techniques such as Photoelectron Spectrometry (XPS), which is employed for PSC, will provide the first-ever visual, topographical, and chemical documentation of pit surfaces. The PSC techniques will expand our abilities in the early detection of irregularities in weapon primaries so that these irregularities may be mitigated or eliminated, through refurbishment for example, in the enduring stockpile.

Investigations being conducted by materials scientists at Los Alamos, Livermore, and the Pantex Plant have provided new data on the corrosion mechanisms for the beryllium pit-cladding material. The XPS electron micrograph shows the presence of chloride on beryllium following exposure to an organic chloride solvent used for degreasing.

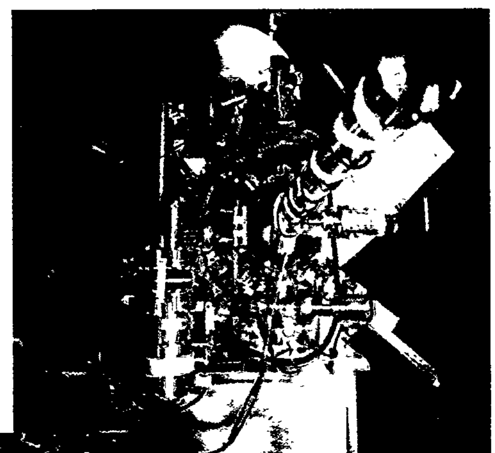


Figure PX01/06a. *(above) X-ray photoelectron spectrometry is one of several techniques that will be used to characterize the surface chemistry of the pit surfaces.*

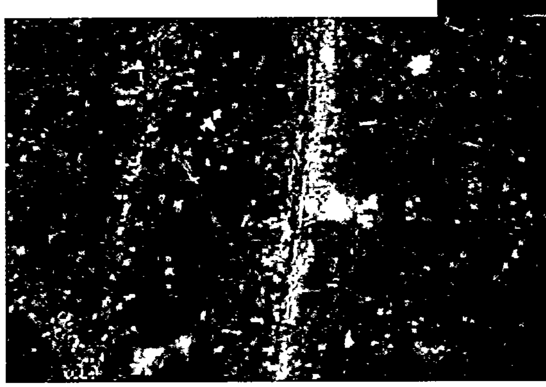


Figure PX01/06b. *XPS image of a beryllium surface exposed to carbon tetrachloride and etched with water vapor.*

Systems Focus Area

Rationale

Several aspects of the ESP require integration across nuclear and nonnuclear components, their surveil lance methods, associated predictive assessments, and other tools in order to provide results optimized at the systems-level for use by the DOE and the DoD. The Systems Focus Area was defined to collect those tasks in coherent groups and to incorporate them into the appropriate level of system integration.

Purpose

Presently three major classes of activities are included in the Systems Focus Area: Enhanced Fidelity Instrument (EFI), Database Management, and Reliability Assessment.

Expected Outcome

A common expected outcome of the three focus areas is the ability to integrate closely related activities across the complex effectively and, at the weapon systems level, to collect, access, and use results of the ESP effectively. Specific outcomes from the individual activities classes include the following:

- A full-spectrum reliability assessment methodology, which integrates advances in evaluating the reliability of the nuclear explosive package with development of predictive reliability methods for nonnuclear components.
- A capability to perform system-level flight testing with the highest fidelity consistent with diagnostic capability for key features of both nonnuclear and nuclear explosive package performance.
- A surveillance information capability that addresses deficiencies in the current information management system including transforming data to information and then to knowledge and assuring needed electronic access, with priorities determined by the surveillance community.

Enhanced Fidelity Instrument (EFI)

It is important for our future confidence in the stockpile to develop the ability to assess the flight test performance of a nuclear weapons system, including all representative components. Diagnostics are needed to assess aspects of system performance and diagnose anomalies. Enhanced surveillance efforts are supporting the development of needed diagnostics and advances in miniaturization, data handling, and intrusiveness-minimization important to realization of this goal. This requires the integration of accountabilities: nuclear, nonnuclear, system integration, and those for DoD.

Deliverable

1. Develop enhanced flight diagnostics for joint flight testing.

Pertinent Tasks

- LA03 Flight Test Program
- SN20 Advanced Telemetry
- LL28 Telemetry Micro-Miniaturization Development
- SN19 System Integration
- LL31 Phenomenology Experiments

LA03 Flight Test Program

HERT (high-explosive radio telemetry) is a telemetry system that measures the initial performance of an explosive package in flight. Such telemetry requires a system with high time resolution, accurate time resolution, and the ability to get the data transmitted before the system is destroyed. The telemetry system should affect the resources of the delivery vehicle as little as possible; size, power requirements, and antenna demands should be as small as possible. A measurement of this type is very risky in that it is measuring the performance of a simple, highly developed and reliable system using a much more complex and less developed component. Thus, the design of this telemetry should be such that the telemetry itself and the sensors are available for testing and possible replacement. In order to simplify the design and fabrication at this time, no attempt is made to measure anything beyond the time of arrival of shock at a specific sensor, relative to another sensor. Because the measurements are taking place in an environment of induced electromagnetic interference, the decision was made to utilize fiber-optic isolation between the sensors and the telemetry package. If the sensor and link could be a strand of fiber optics, the ideal of simplicity and reliability could be approached.

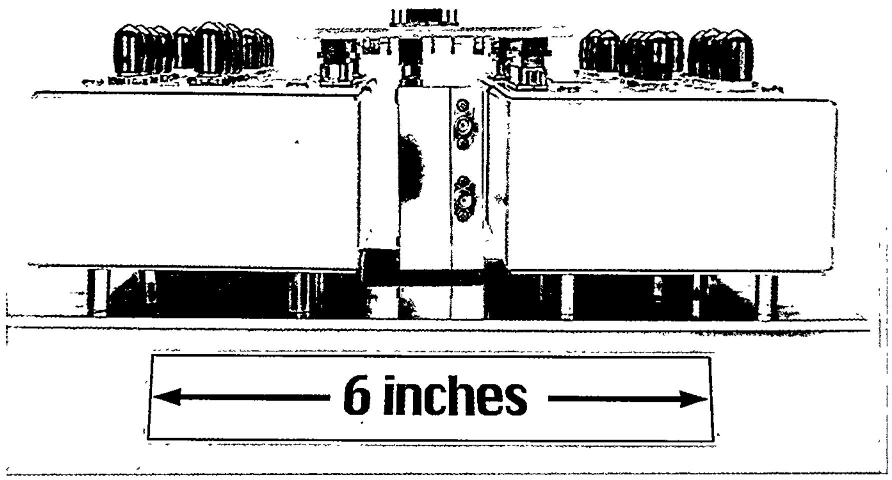


Figure LA03. *The first prototype telemetry system used in HERT explosives tests. The small box in the center is the TM package, larger boxes on each side are fiber-optic inputs.*

In the past, the plans for the development of HERT from an experimental concept to a flyable component consisted of feasibility, acceptability and developmental stages. The results of HERT 1, 2, and 3 tests have convinced us that the concept is feasible. We have combined some of the testing from the last two stages and have conducted flight tests with Sandia using their ground station, which duplicates the actual receiving stations in the field.

The second stage, "acceptability," consisted of testing configurations with the best technology available to determine if the actual data obtained from the test are useful to the designers in certifying whether the system performed properly. We have broken the "acceptability" stage into two parts, the "planar" tests and the "representative geometry" tests. Four tests under HERT 3 were conducted last winter (1997) using a "planar" configuration with good results.

The first two tests of the HERT 4 series were successfully conducted on July 23, 1997. These tests provided very valuable information about the unsuitability of air-gap fiber-optic sensors. It is planned that by the end of the HERT 4 series of tests (June 1998), a sensor selection will have been made and at least one test conducted where the telemetry will be placed at a representative distance from the charge and destroyed by the explosion. By this time, we should have enough data to begin designing meaningful "representative geometry" tests.

We have done reasonably well in including all of the DOE organizations into this effort. Los Alamos, the Kansas City Plant, Sandia, and Livermore have all contributed to and participated in the efforts thus far. We will need more input from the weapons design and testing people and the DoD as we progress into the final stage.

System Integration and Advanced Telemetry

When the W87 is deployed on the Minuteman III as a single reentry vehicle, joint test assembly (JTA) flight opportunities will be reduced to as few as 2 flights (two reentry vehicles) per year. An instrumented, high-fidelity JTA design is needed to collect all data required for DoD and DOE to certify the reliability of the W87 system in this reduced-flight-test environment. The enhanced fidelity instrumentation (EFI)/advanced telemetry project is providing flight instrumentation to enable the development of a W87, instrumented, high-fidelity JTA flight test vehicle. This JTA will be virtually indistinguishable from a WR reentry vehicle, although it will provide instrumentation to monitor required DoD and DOE functions including physics diagnostics. Technologies developed with this project will enable the development of high-fidelity flight instrumentation for all weapons in the enduring stockpile. In the near term, this will include telemeters for the W80 JTA, the W76 Dual Revalidation Program, and the Warhead Protection Program.

The EFI-1 instrumentation suite provided the capability to measure both functional and dynamic phenomena. This early version of the EFI/advanced telemetry utilized some previously developed terminal data acquisition instrumentation in order to meet a compressed test schedule. Though the EFI-1 design effort and hardware fabrication was successfully completed, the W87 test that was intended to field the EFI-1 instrumentation suite (Flight Test Unit-11—FTU-11) was canceled.

EFI-2 is the first telemetry system to be fully contained in the weapon pit. The EFI-2 provides the capability to measure limited warhead dynamics. The EFI-2 design is complete and is currently undergoing qualification testing (FTQU-12) in preparation for a May 1998 flight test (FTU-12) and a September 1998 flight test (FTU-13).

The EFI-3 design effort will yield a telemeter that is fully contained in the pit with the capability to collect all functional and dynamic data required to certify the W87. This design will also provide the basis for telemeters to support multiple weapons programs, including the W80, W76, and WPP. The EFI-3 will fly for the first time on FTU-15 and FTU-16 in September 1998.

Though the EFI-3 design provides all data required for weapon certification, it precludes advanced pit implosion diagnostics because the instrumentation is contained in the pit. The recently initiated EFI-4 design effort will yield a telemeter that collects all data required for certification but also permits the incorporation of advanced pit diagnostics, including a full, live IHE main charge. The EFI-4 will fly for the first time on FTU-17, currently scheduled for September 1999.

This task is performed in cooperation with LL28.

Miniaturizing Flight Test Instrumentation

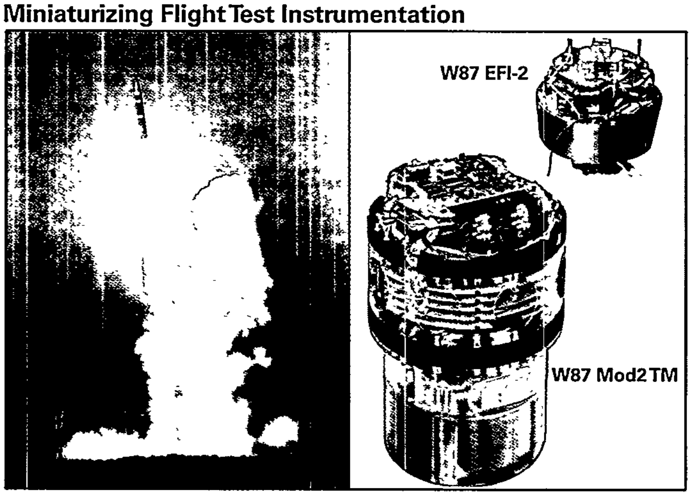


Figure SN19/20. *The W87-EFI miniaturized telemetry package will be flown on the peacekeeper missile.*

LL28 Development of Microminiaturized Telemetry

We have accomplished a great deal towards flight-testing instrumented, high-fidelity joint test assemblies (JTAs). We have established the direction of future telemetry to meet new requirements and to prepare for reduced flight test opportunities in the future resulting from Start II and Start III treaty limitations. We have developed new technologies that enable instrumentation of high-fidelity flight test configurations for the first time. Our developments will impact the W87 Life Extension Program with a first flight of an instrumented, high-fidelity configuration scheduled for May 98.

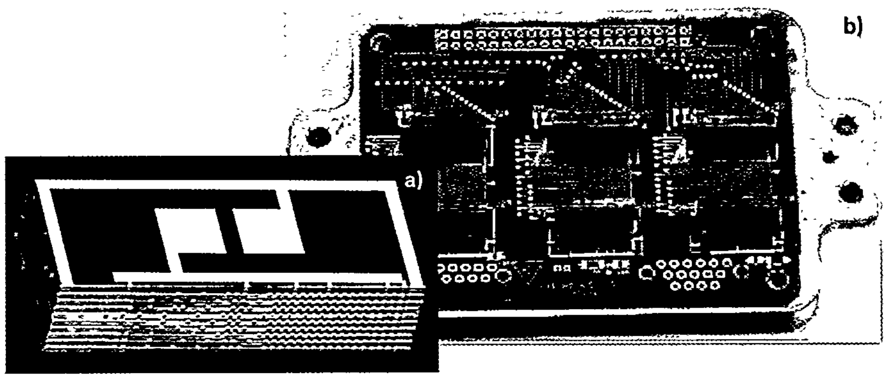


Figure LL28. *a) Unpackaged diced-memory integrated circuits are stacked in a 3-dimensional dense pack. Signal traces are rerouted and interconnected by precision laser pantography along the edge of the stack. b) Stacks of bare memory die are attached to a flexible circuit interconnection and mounted on a printed circuit board as part of a 1-gigabyte telemetry, bulk memory system. Memory control circuits are mounted on the other side of the circuit board.*

We have extended the Livermore-developed laser pantography technology for dense packaging of telemetry electronics. We developed the ability to fabricate 3-D packing of unpackaged integrated circuits. We designed, developed, fabricated and tested high-density memory stacks for telemetry applications. Testing continues with the support of the Kansas City Plant.

We have developed the requirements for on-board memory for telemetry. We've engineered, designed, and fabricated a 1-gigabit memory subsystem (Figure LL28) based on memory stacks fabricated at Livermore. This capability enables data collection for flight tests of strategic weapons over broad ocean areas and longer flight tests of JTAs on cruise missiles where telemetry transmission and reception can be deferred until the test object is down range.

We have researched and specified the requirements for new on-board sensors for the NEP and the reentry vehicle. Sensors for flight dynamics and weapon function have been tested in ground tests and evaluated. Their performance has been modeled for development of supporting signal-conditioning circuits, and for post analysis of flight test data. Candidate sensor technologies have been selected and supporting signal conditioning designed and tested in ground tests and in flight test configurations.

New, distributed telemetry system models have been developed and are being evaluated for application to instrumented, high-fidelity JTAs supporting terminal-event data collection on a JTA with a full HE charge. We have evaluated mechanical mounting and interconnection of telemetry and sensor components, and we have designed penetrations, interfaces, mounting, and attachment to NEP systems to be monitored.

Database Management

Access to a variety of weapons databases is needed in order to make rapid, informed decisions on matters affecting nuclear weapons safety, reliability, and compatibility. Many existing databases need modernizing, and much of the body of data is not yet in electronic form. The first responsibility of surveillance information activities within the ESP is to define the necessary requirements and priorities for data access for future use by surveillance activities within the DOE complex. Some of the individual agency tasks will also prototype a cost-effective, intuitive, desktop capability to access surveillance-relevant weapon information in both classified and unclassified environments. The principal focus of nonnuclear information activities is to develop the tools needed to assess trends in weapons surveillance databases cost-effectively. The purpose of the tasks within this group is to meet the needs of the individual agencies while maintaining a complex-wide focus. These activities will be appropriately coordinated with related activities funded by individual site overhead funds, by the ADAPT and ASCI programs.

Deliverable

1. Specify information requirements for surveillance activities and coordinate these requirements with other programs.

Pertinent Tasks

- **OR01** Historical Certification Data Analysis
- **OR03** Analysis of Shelf-Life Data
- **SN15** Data System
- **LA14a** Material Property & Surveillance Database
- **LA14b** Surveillance Information Group (SIG)
- **LL27** Database Management Systems (DBMS)
- **PX04** Weapons Data Information System
- **KC04** Remote Database Access for Enhanced Surveillance
- **PX05** Video Capture Storage and Retrieval

OR01

Review and Analysis of Production Certification Records at the Y-12 Plant

We have developed a methodology for evaluating aging in weapon systems using a combination of certification data (generated at the time the canned subassembly (CSA) was produced and before it was fielded) and surveillance data (generated when the unit is removed from the stockpile). This methodology has led to two break-throughs. The first is a process for identifying specific candidates for destructive evaluation, thus maximizing aging information gained from the Core Surveillance Program (CSP). The second is the discovery of a correlation that could allow us to screen stockpiled units nondestructively and remove high-risk units selectively from the stockpile. There is currently no such nondestructive technique.

The process involves a systematic review of the certification records of different weapon families and was developed to identify particularly "interesting" candidates in the stockpile for destructive evaluation. It is hoped that this review will lead to an aging assessment of the individual weapon families and to an enhanced overall understanding of CSA aging. An example of the approach used to identify candidates is illustrated in the adjacent figures. Recent results indicated there appears to be some connection between the certification measurement made at the time the CSA was produced and the rate the unit aged in the field. One of the surveillance units disassembled a few years ago, identified by the arrow in Figure OR01b, had an unexpectedly high aging rate. As can be seen, it was also one of the CSAs toward the extreme right end of the curve in Figure OR01a. Since then, other units in this high-risk aging group were nondestructively examined at Pantex. Two units appeared also to have been aging at a rate higher than expected and have been removed from the stockpile. Plans are to send these units to the Y-12 Plant for additional evaluation.

More recently, the certification records of another weapon family were reviewed. In combining the certification records with the surveillance results, we discovered a correlation between two measurements made at the time of disassembly. The correlation links CSAs from different weapon families and, if valid, enhances our overall understanding of CSA aging. Moreover, based on this correlation, a nondestructive method can be developed to screen for high-risk aging units in the stockpile. To validate the interpretation, other candidate CSAs have been identified for disassembly and admittance to the shelf-life program.

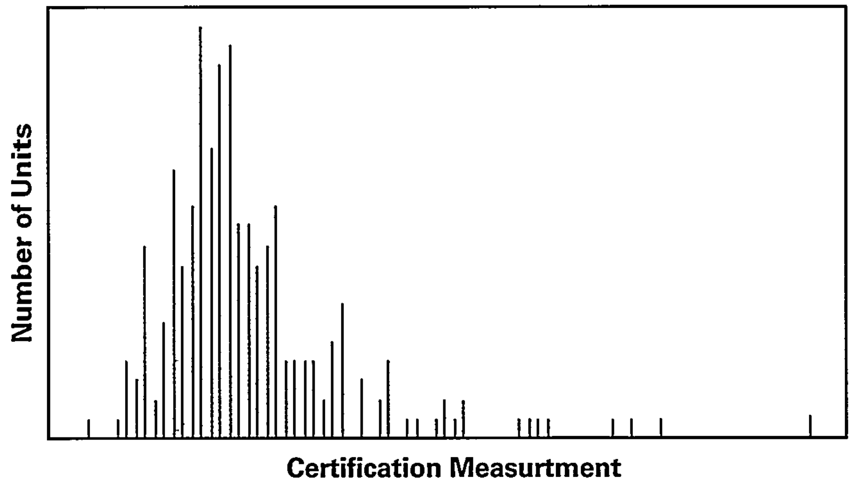


Figure OR01a. *Distribution profile based on historical production records.*

We also made an initial effort to make an aging assessment. An aging assessment framework was first developed based on a known failure mode (Figure OR01b). This framework serves as a focal point to identify additional information needed to test the underlying assumptions made in the development of the framework. It can serve as an efficient vehicle for improving our overall understanding of CSA aging and for making more reliable assessments in the future. A classified report is being written to document this effort.

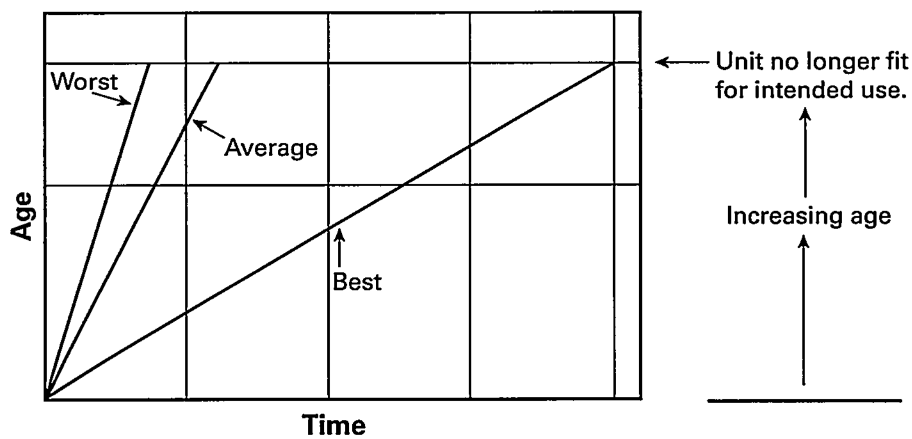


Figure OR01b. *Aging access framework based on known failure modes.*

LL27 Database Management Systems

This task included the scanning of over 400 documents (~ 9000 pages) and putting them on-line on the classified network at Livermore. This recorded for each document the Nuclear Weapon Information Group (NWIG) metadata associated with that document and demonstrated that it was technically feasible to scan entire vaults of classified documents, recover the text in those documents, and make the documents available on Web servers. The experiential system developed by this task can search all of the text in the scanned documents using any one of three full-text commercial search engines. The metadata associated with the documents can also be searched using substring matching on any NWIG field in the metadata database that was developed by this project. This task also helped to develop the approval process for getting Web servers up on the Livermore classified network.

We developed a Web-based system for uploading and storing classified documents on a Web server. The approach uses the latest Web-based certificates to authenticate the users and prevents anyone except the authorized document uploader from uploading a document. The system is designed so that digital signatures for the review and release process can be incorporated into it as soon as the standards for these signatures are in place and the software for providing them is available. This system captures the full set of NWIG metadata as the document is uploaded and allows that information to be searched.

We are working with other NWC sites to develop an unclassified network with restricted access. Following the SecureNet model, the network uses Energy Science Network (ESNet) as the communication backbone with data encryption standard (DES) encrypters at each end protecting the information. Kansas City agreed to be the central site for managing the encrypted communication. Livermore has taken delivery of its DES encryption box and plans to install and test the system with Kansas City during August.

During the course of working on the tasks listed above, we have identified, selected, and evaluated the best available Web-based technologies. We have put together both classified and unclassified Web servers that hold the data for the systems described above. We have developed the procedures that will enable us to quickly roll out new applications based on this advanced technology and have selected the technologies and designed the systems with the future in mind such that all of the systems are based on standards that are widely used and that will be around for a long time.

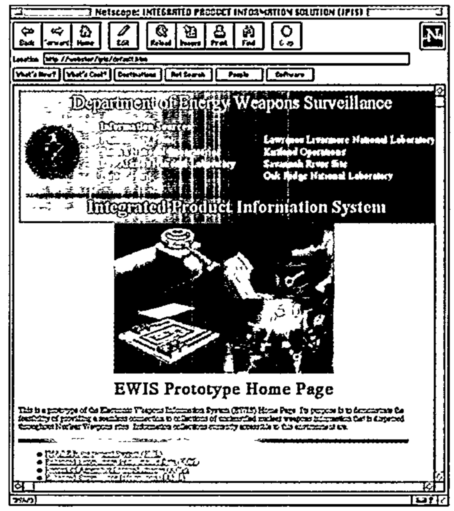


Figure LL27. *Web-based database of stockpile surveillance documents. Over 400 documents have been scanned into the database, which can be accessed only by authorized users.*

Reliability Assessment

The primary focus of this effort is to gain a better understanding of stockpile reliability, including current reliability assessment and predictive reliability assessment. A critical understanding of system performance (both nuclear and nonnuclear) related to weapon stockpile reliability provides important data to use in assessing the integrity of the nuclear deterrent. Current reliability estimates for the nuclear package have historic roots that may not be entirely appropriate for lifetimes significantly longer than anticipated when the weapon was designed. Nonnuclear reliability tools presently lack the ability to incorporate age-aware performance models, performance trends, and early indications of unacceptable changes to provide predictive reliability assessments past the originally protected period.

Deliverable

1. Gain a better understanding of stockpile reliability.

Pertinent Tasks

- **LA23** Enhanced Reliability Methodology Pilot Program
- **SN18** Augmented System Reliability Toolset

LA23 Enhanced Reliability Methodology Pilot Program

The objective of this task is to develop and test a structured, quantitative approach to modeling the reliability of the weapon system nuclear package. This modeling approach involves using expert judgment when test data are not available.

Los Alamos developed the enhanced reliability method (ERM) to obtain reliability and uncertainty estimates of weapon components and/or systems. Reliability is defined as the probability that a nuclear package will produce the certified yield. The method provides a database, logic model, and statistical techniques for combining information of various types into an overall reliability estimate. Additionally, the ERM supplies a detailed textual record of the information on which the reliability estimates are based; this text can be used as archives to generate reliability reports for weapons research. The ERM offers a systematic and quantitative way to evaluate the effect on the reliability of such actions as replacing a component or conducting additional studies and testing. The approach is being applied first to the W76 and will provide a reliability assessment of the W76 nuclear package.

The reliability and uncertainty estimates are provided for each nuclear package component or subsystem by weapon experts during formal, structured interviews. The experts base their estimates on the available relevant information from nuclear and non-nuclear tests, numerical simulations, material properties, communications with colleagues, and production and surveillance data, and on their assessment, synthesis, and interpretation of this information.

The ERM contains an elicitation technique, "rule-based performance prediction," which can also be used independently of the larger method. Rule-based performance prediction provides rules on how nuclear package conditions relate to performance. The performance predictions can then be used to generate uncertainty distributions for reliability. The technique provides a means for forecasting reliability as a function of the components' expected conditions. Forecasts have been obtained using hypothetical component conditions.

The rule-based technique involves interviewing the expert on the selected component or subsystem to learn which conditions would lead to degraded yield establishing fuzzy rules on these conditions (e.g., if *x* condition is high and *y* condition is low, then yield is low), having the expert assign numbers to these rules, and generating the output—plots of yield as a function of the conditions with the associated uncertainties.

The enhanced reliability method is being tested or validated in another setting, that of the automotive industry, where test data are more plentiful. The aim is to check engineers' early reliability estimates against subsequent test results for a new fuel injection system.

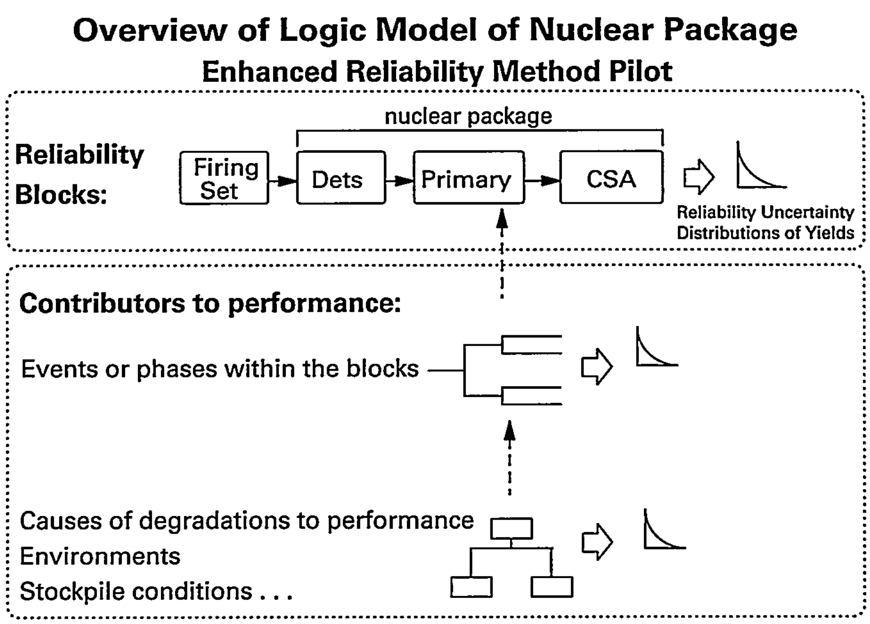


Figure LA23. *Overview of logic model of nuclear package, enhanced reliability method pilot.*

Secondary-Specific

Assuming nonnuclear firing devices and the primary portion of a nuclear weapon function as designed, the yield of the weapon depends upon the performance of the secondary. The secondary is a complex device with several potential avenues for performance variation because secondaries are composed of many materials and components assembled in a variety of ways. The assembled unit must be geometrically precise, and the materials included must remain in their as-designed, as-installed condition to meet performance expectations. Historical surveillance data have revealed evidence of materials interactions that may affect performance of the secondary in the aging stockpile. The secondary program is benchmarked in these observations and in investigation of other potential areas of concern, to begin to answer the challenges to our ability to certify the stockpile's reliability as it ages in the future.

The Lawrence Livermore and Los Alamos National Laboratories and the Lockheed Martin Y-12 Plant are collaborating in the ESP tasks for secondaries. There are tasks originated by each of the sites. Collaborating principal investigators are named on all tasks. The secondary program element for ESP has been gaining strength through FY97 with several important accomplishments already affecting the routine surveillance testing program. The secondary program element for ESP is a mix of 1) materials science, 2) supportive experiments, 3) data analysis (historical and new data), and 4) modeling. These secondary-specific activities are integrated closely with related activities in other program elements, for example, diagnostics. The overall objective is, of course, to develop understanding of the aging of materials, components, and systems sufficient to make assessment and prediction of performance for decades to come. Past knowledge and experience have been bounded by relatively short stockpile lifetimes because weapons were replaced with new designs. Modeling and prediction based on several decades of performance were adequate. This is not the case in the future, and ESP fills this new challenge. Performance models are constantly being improved and benchmarked against new data being generated by ESP tasks. By approximately 2000, performance models for secondaries will be published. Recognizing that prediction is not 100% accurate, new stockpile surveillance techniques are also being developed to give early indication of any adverse changes in components. This is reflected in ESP's diagnostic element.

Deliverables

1. Results of experiments that characterize the chemical, physical, and mechanical changes that may occur as a result of aging.
2. Reports that describe the changes that might be expected as a result of aging in constituent components.
3. Predictive models that include aging mechanisms of the actual secondary configurations and can be used to assess the expected life of secondary components.

Pertinent Tasks

- **OR07** Hydrolysis Reaction of Material
- **OR02** Interrogation of Dismantled Units
- **OR14** Materials Properties Evaluation of U Components
- **LA10** Materials Study on Special Material
- **LA15** U Corrosion and Aging
- **LA22** Aging of Special Material
- **LL20** Decomposition and Interaction in Materials of Interest
- **LL23** Atomic, Site-Specific Chemistry and Physics
- **LL22** Modeling of Materials of Interest

LA15 Uranium Corrosion and Aging

The aging characteristics of materials in a weapon's secondary affect the life and potentially the performance of components. However, the degree of aging response is dictated not only by baseline properties as a function of time and environment, but also by assembly conditions and the pedigree of the base material. Specifically, processing, handling, and environments are all variables to evaluate in developing accurate lifetime predictions of secondary components.

Uranium has a variety of processing-specific pedigrees. For example, variations in carbon contents (and other trace impurities) as well as thermal histories are quite common. As a result, significant microstructural variations, and therefore property variability, exist in components simply categorized as "uranium." Any evaluation of aging characteristics must include microstructure variables.

The corrosion and aging of uranium has been categorized into two main areas: surface behavior and bulk behavior. Certainly, the bulk metallurgical aspects of microstructure govern aspects of the surface response. As a result, baseline studies in conjunction with simulated aging environments have been performed to delineate key variables consistent with phenomena observed in surveillance activities. Highlights of these efforts include the following:

- The simulation of thermal history evolutions of various uranium pedigrees to provide a realistic test matrix of samples;
- Characterization of baseline mechanical properties as a function of performance strain-rate conditions; and
- Performance of laboratory simulations of nucleation of pits as a result of hydride formation and as a function of sample pedigree.

The latter highlight is of particular significance in that a unique in situ analytical tool has been developed that enables direct observation of hydride formation on a pit under very controlled temperatures, times, and environments. In general, these results indicate that the nucleation of hydrides on uranium surfaces exhibits a sensitization phenomenon that is strongly dependent on the surface state. Furthermore, the growth kinetics of the nuclei are a function of the pedigree. Finally, the stress states accompanying the local distortion from the volumetric change of the hydride result in an autocatalytic pit growth. An example of this is shown in Figure LA15.

These tasks are being complemented with recently established high-resolution surface analysis techniques that focus on the chemistry and structure of the active nucleation sites. These efforts are also being performed in conjunction with a statistical evaluation of available stockpile uranium chemistries and investigations of stockpile material.

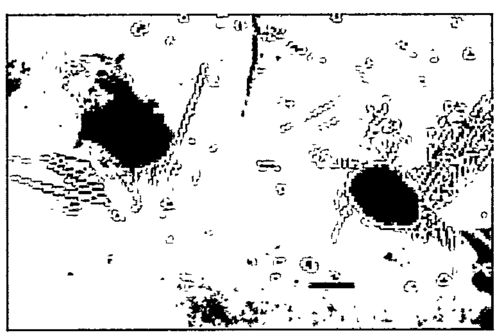


Figure LA15. *Hydride pits on a uranium surface.*

LL20 Decomposition and Interactions in Materials of Interest

We have developed an improved technique for characterizing outgassing kinetics. Accurate activation energies for salt outgassing are essential for stockpile-aging models. Using previously determined activation energies along with the absolute reaction rate at a given temperature allows the salt outgassing rate to be predicted as a function of time and temperature for stockpile. This in turn can be used with other CSA material properties to predict failure rates. A system has been built and used to determine the rate of salt outgassing as a function of time and temperature. Its use in measuring the activation energy is illustrated in Figure LL20. State-of-the-art analysis of the interaction of moisture with salt and CSA organics requires the precise control of moisture environments. We have put together a system that will allow us to control moisture levels in small and large chambers. Control range is from 1 ppm to 100% relative humidity.

We have also developed a new materials-characterization technique. Moisture carried into a CSA by organics is eventually converted to hydrogen, a source of corrosion for uranium. Knowledge of the moisture content of CSA organics is essential for stockpile-aging models.
A vacuum-system-based, mass spectroscopy technique was developed to determine the moisture content of materials under a variety of exposure conditions.

Using irradiation models and threshold dose data from the literature, we carried out a study to determine if any organics in a Livermore-designed CSA remaining in the enduring stockpile were at risk from irradiation damage. The study identified only two candidates. To determine if significant changes might be expected in the coming decade, samples of these materials were recovered for analyses that may continue into FY98. The results may lead to the implementation of new surveillance tests for this CSA.

A review of surveillance data was carried out to identify possible overlooked aging issues with any organics in a Livermore-designed CSA remaining in the enduring stockpile. Only one was identified: the embrittlement of a toughened silicone rubber component. This result was observed in two AAUs, but not in normal surveillance units. Arrangements have been made to recover samples of this material in FY97. Analyses may continue into FY98.

The ability to manually inspect LiH specimens for LiOH has been achieved. The technology in concept, hardware, and software for automatically mapping LiH surfaces for LiOH also has been achieved. Locating this functional, automated hardware in a very dry glove box that is both secure and approved for use with radioactive material is underway and should be achieved in FY97/98. Automated facilities operating in the glove box for mapping coupons for core test components should be available by the end of FY97.

Outgassing Profile

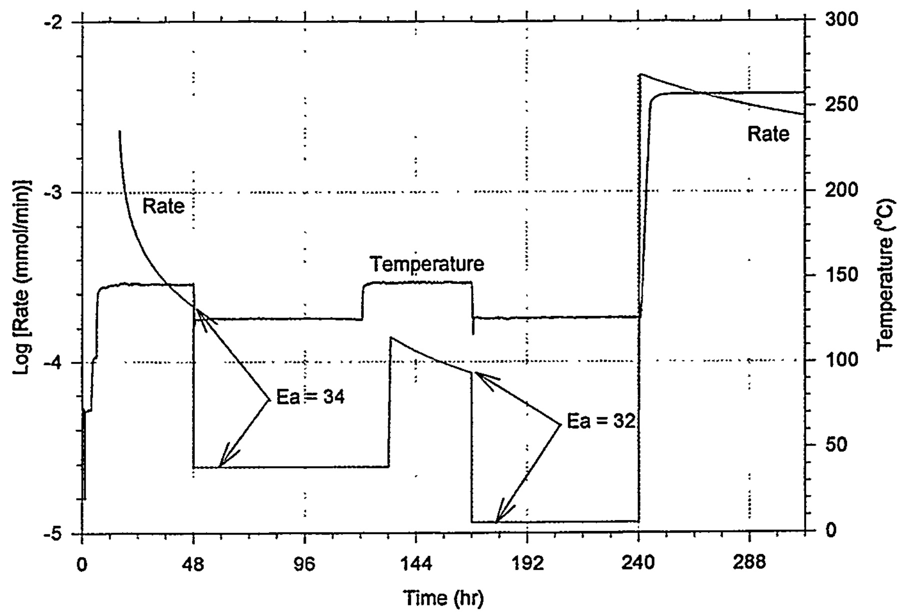


Figure LL20. *Using a reaction-quenching technique, the activation energy, or temperature dependence of the salt outgassing reaction can be determined. This is accomplished by first measuring the rate of pressure rise at one temperature, then rapidly cooling the reaction and measuring the rate of pressure rise at a lower temperature. Because the reaction is proceeding at a significantly slower rate at the lower temperature, the extent of the reaction is nearly the same at the two temperatures. Thus, by comparing the final reaction rate at the upper temperature with the reaction rate at the lower temperature, we can determine the Arrhenius activation energy.*

Interrogation of Dismantlement Units

Under the Interrogation of Dismantlement Units task,we are currently investigating the recoverability of materials and components from canned subassemblies (CSAs). Dismantlement offers an unprecedented one-time window to assess the aging of materials and components in the stockpile well beyond their initial design lives. The existing stockpile is the only practical source for real-time-aged components and materials and the sole source for certain key materials of war reserve quality.

The CSA components recovered under this task are being used in other ESP tasks to establish benchmarks and predict the aging of weapons in the enduring stockpile and to evaluate the recycle/reuse potential of weapon components. New surveillance techniques using CSAs are also being evaluated.

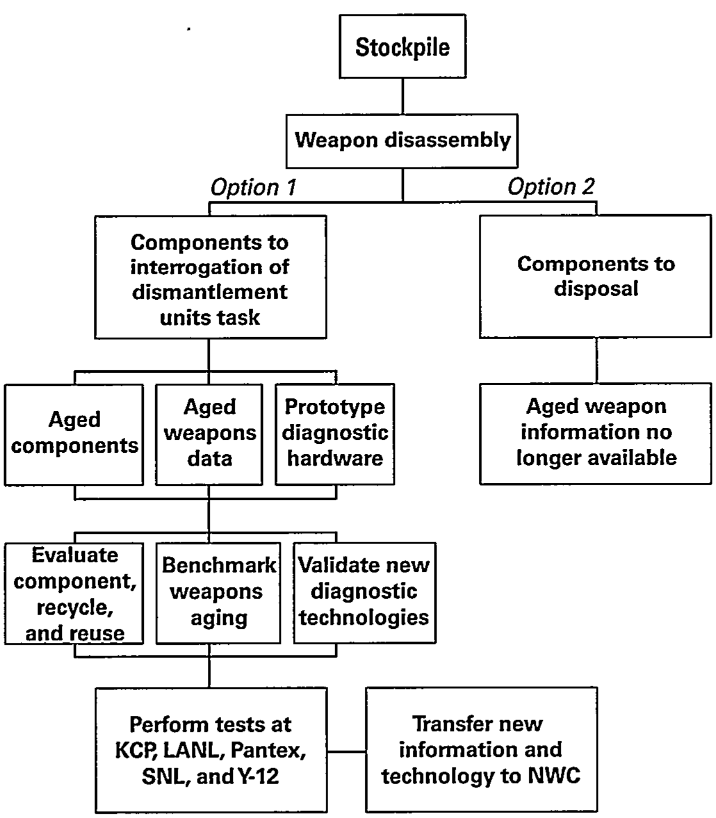


Figure OR02. *Flow chart showing increased component utilization as a result of efforts of OR02.*

Accomplishments to date include the following:

- The creation of an interface between design agency and production plant ESP task leaders. This interface role provides, through an off-site assignment at Los Alamos, a mechanism through which ESP task leaders can capture components, materials, and information necessary to accelerate the completion of their tasks and/or the deployment of their new surveillance technologies.
- The leveraging of ESP resources with design agency resources to provide components and information. This effort provided valuable components to special production projects at design agencies and also provided weapons information to accelerate the closing of Core Surveillance Significant Finding Investigations.
- The leveraging of ESP resources with disassembly operations resources to develop and evaluate prototypical hardware for enhanced surveillance. These interrogation techniques include the low-temperature thermal decomposition system, which provides differentiation of chemical species important to surveillance, and a video imaging system.
- The transfer of 16 weapon components to ESP task leaders. Components with well-documented part histories were transferred to the task leaders of Polymeric Materials Aging, Hydrodynamics, Aging of Special Material, and Flight Test Early Tasks for testing. The ESP leveraged its resources with Y-12 Operations resources to manufacture storage containers to ensure integrity of these components. Fifty-three additional components were also identified for ESP tasks, and protocols for capturing and delivering these are being implemented.
- The transfer of the Los Alamos weapon database management technology information to the Oak Ridge Y12 Plant for weapons disassembly data archival and reporting in digital form. Hardware and software information, compact disc publishing and labeling protocols, image and video creation techniques, and digitized copies of surveillance reports were transferred from the Los Alamos pit surveillance group to the Oak Ridge Y-12 Plant.
- The procurement of an enhanced infrared diagnostic tool for component surveillance. This instrument, an enhanced Fourier Transform Infrared Spectrometer (FTIR), will be delivered in 1997 and prototyped in Y-12 disassembly operations. This FTIR development, a joint effort between Los Alamos, Y-12, Surface Optics Corporation, and the Oak Ridge Center for Manufacturing Technologies, provides real-time, on-line diagnostic capabilities for evaluating aging effects on enduring stockpile weapon components.

Modeling of Materials Compatibility

This project addresses the modeling of material aging in the canned subassembly. This is a closed environment, where a welded can prevents the interaction of the materials with the external atmosphere. Our efforts have been focused on the development of a "system" model for this closed environment. The chemistry of the component materials, in isolation, indicates that they are nonreactive or essentially inert. The two areas that need to be addressed are the interaction between the materials and their interaction with the gases left in the subassembly during assembly. These areas will most likely be the ultimate cause of failure resulting from aging. The time it will take for this to occur is important for scheduling remanufacturing.

This project's goal is to develop a comprehensive computer model of the chemistry in this sealed environment. The materials involved are solid components with small gaps between them through which gases can diffuse. Our efforts have been focused on developing models for the reaction of gases with the solid materials and on the diffusive transport of gases through the geometry of the subassembly.

The reaction of gases with metals is a complicated process. There is frequently a layer of oxide on the metal that causes the reaction to occur nonuniformly. We have been developing a model for this process. Figure LL22 shows snapshots from a two-dimensional version of the model, where "pitting" occurs. The model will be calibrated using the experimental results from Task LL23, "Atomic Site-Specific Chemistry and Physics (not included in this report).

As stated above, the reaction models need to be incorporated into a larger model of the transport and reaction of gases in the geometry of the system. The equations that describe the diffusion of gases are, at their basic level, the same as the equations that describe thermal diffusion. Livermore has developed a suite of computer codes for the calculation of mechanical properties of materials. The thermal diffusion code is TOPAZ. Using the program for diffusive gas transport is complicated.

We have demonstrated that this approach will, in fact, work. The complications arise in that the gas pathways are small narrow gaps between largely impenetrable solids. The resulting grid for the computer code is, essentially, the opposite of what the code was designed for. We have been able to show that by careful grid development gas transport can be modeled. Detailed models of the transport paths in a subassembly were produced.

The ongoing work includes the creation of advanced gas-solid reaction models and, more importantly, the modification of the computer code to include these models.

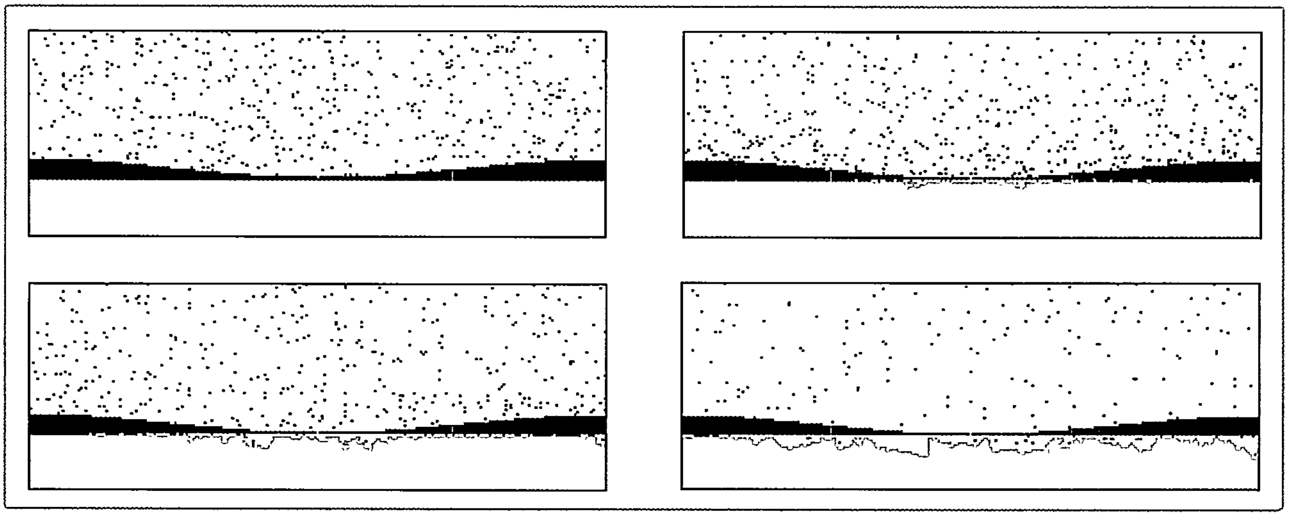


Figure LL22. *Snapshot of a material surface hydriding in the presence of a layer of oxide. The red particles represent hydrogen, the purple overlayer metal oxide, green is pure metal, and yellow is the hydrided metal. The sequence is from left to right and top to bottom.*

Materials-Aging Models

Rationale

The reliability and surety of nonnuclear components and subsystems in the enduring stockpile will change with time as a result of the age-related degradation of their constituent materials. Existing stockpile assessment methods typically address materials-aging and reliability problems *after* they occur, rather than anticipating and avoiding future problems or failure mechanisms. Materials-aging models focus on improving our ability to anticipate surety and performance-reliability problems caused by materials aging.

In order to predict and thus avoid or correct reliability problems in the surety and performance of weapons, significant improvement must be gained in modeling and simulating the behavior of materials as they age in the stockpile environment. Detailed understanding of materials encompasses the signatures of aging and degradation phenomena and projecting these phenomena out to eventual failure. The Materials Aging Modeling Focus Area supports investigations to improve the fundamental understanding and modeling/ simulation of materials-aging behavior in stockpile environments. Individual tasks emphasize the prediction of failures that affect the surety or reliable performance of weapons. Supported investigations focus on quantifying the difference between "performance requirements" and "performance limits" (i.e., the "failure envelope") and how these change with time. This understanding is necessary to extend the lifetime of weapons in a safe and dependable manner. The relevant *integration* of materials understanding, materials modeling, and performance simulation is the hallmark of this focus area.

Purpose

Five principal categories of time-dependent changes in stockpile materials are being addressed. Our selection of these R&D categories is the result of a risk assessment of stockpile materials, which identified materials with the highest likelihood of age-related changes and with the highest consequence of materials changes. Likelihood of aging is based upon a combination of data from the stockpile surveillance history and engineering judgment based upon our present understanding of the kinetics and thermodynamics of given materials degradation mechanisms in stockpile environments. Evaluation of the consequence of aging is based on our understanding of the design intent of the material in the given weapons application, the impact of degradation on safety and reliability, and of other related factors. Objectives based upon these five identified categories are as follows:

1. **Energetic Materials Models** - Energetic materials are chemically and morphologically metastable. A wide variety of such materials serve important initiation, actuation and propulsion functions in nonnuclear components, including driving the fireset function, powering spin rocket motors and gas generators, operating mechanical switches and use-control devices, and firing thermal batteries. Degradation of function both in terms of energy density or timing would degrade system reliability. Increasing sensitivity to initiation over time would also degrade weapon safety. Additionally, gaseous degradation products pose compatibility issues for weapon electronics and other sensitive materials. We will develop rigorous understanding of and predictive aging models for energetic materials in nonnuclear components. We will assess potential surveillance methods for the detection of early signatures of unacceptable changes in these materials.

2. **Organic Materials Models** - Organic materials are susceptible to embrittlement and other significant physical property changes with time. Cracking in cables or in dielectric materials in weapon capacitors could lead to shorts, interrupting a firing signal. Failures in O-ring seals degrade the environment of components protected by those seals. Aging in materials used for encapsulation will jeopardize the reliable performance of the system in STS environments, particularly with respect to impact requirements. We will develop a predictive understanding of the highest risk/failure modes resulting from aging organic materials. We will establish benchmarks for required physical properties and develop methods to detect early changes.

3. **Solid-State Materials Models** - Weapon electronics are highly sensitive to time-dependent physical/ mechanical changes that occur in their constituent materials. Three failure modes of concern are the following: (1) thermo-mechanical fatigue of any of the numerous soldered

interconnecting joints essential for weapon performance; (2) loss of electrical continuity as a result of stress voiding of integrated circuit metallization; and (3) diffusive degradation of thin- and thick-film network materials used in weapon microelectronics. Early signatures of each of these processes have been observed in weapon development programs. Significant lifetime extensions require a predictive understanding of these cumulative damage processes. We will develop and validate the needed materials-aging models.

4. **Corrosion Models** - Many metals used in nonnuclear components undergo corrosion in weapon storage environments. Generally, environments in nonnuclear subsystems are not controlled to the extremely high levels of the nuclear explosive package. Documented cases include corrosion of igniters, switches, diodes, integrated circuit packages, resistors, and housings. If the corrosion is sufficiently severe, some form of electrical failure is probable. With stockpile lifetime extension, corrosion becomes an even greater concern than it has been in the past. Complex factors are involved in the initiation of corrosion processes. We will develop a quantitative understanding of the atmospheric/environmental conditions and time required for significant corrosion of susceptible stockpile materials to occur. The tools developed in this program will form a foundation for understanding and modeling atmospheric corrosion of a wide range of materials used in weapons. We will evaluate and select an optimal corrosion risk-management strategy, considering the relative value of predictive modeling efforts, in situ monitoring methods, and/or augmented surveillance procedures.

5. **Interface Models** - Interfaces between dissimilar materials are prone to failure, especially as weapons age. A wide variety of such interfaces and potential time-dependent failure modes exist, including cracking in ceramic and glass-to-metal seals, loss of critical mechanical joints as a result of the failure of adhesives, premature functioning of certain use-control devices as a result of interface separation, and lock-up of a strong link as a result of degradation in solid-film lubricants. We will determine the time-dependent phenomena leading to these failure modes and develop needed estimates of the time scale for loss of confidence in the materials.

Expected Outcome

We will develop and validate age-aware materials models that will be used in quantifying the useful service lifetimes of nonnuclear components and subsystems in the enduring nuclear weapon stockpile. Confidence bounds related to production or environmental variability will be accounted for. Where time-dependent changes in the structure and properties of critical weapon materials cannot be modeled with confidence, appropriate materials characterization tools and surveillance methods will be identified that provide early signatures of aging. Models developed will be incorporated into higher-level electrical and mechanical models for component and subsystem performance (developed in the Nonnuclear Component/Subsystems Focus Area to support the prediction of overall changes in system reliability with time.

Deliverables

1. Develop and validate kinetic model of intermetallic compound growth and microstructural coarsening of B61 radar solder joints.
2. Correlate variations in capacitance and acoustic transmission with variations in output current in SFE firesets.
3. Demonstrate that slim-loop ferroelectric (SFE) material does not degrade significantly and has no time-dependent effect on nuclear safety in the W76 and W78 systems.
4. Identify stress voids in aluminum interconnects in SA 3000 integrated circuits obtained from WR stores.
5. Design, build, and test a Kossel-based microscale strain detection system for measuring stress in aluminum integrated circuits interconnects with high spatial resolution.
6. Identify morphological changes and chemical decomposition pathways in a thermally aged pentaerythritol tetranitrate (PETN) blend, which is used in the SFE firing set explosive lens.
7. Develop an optically responsive NO_2 sensor material with a detection limit of 10 ppm and couple this sensor material to a fiber optic detection system.
8. Develop and validate a theoretical model for diffusion-limited oxidation of polymers, and use this model in the prediction of residual lifetime of O-rings in weapons.
9. Measure the relationship between surface composition and tribological performance resulting from oxidation of MoS_2 on steel and CuBe substrates.
10. Quantify electrical contact resistance and residual surface contamination for stockpile-returned electro-mechanical devices from the B61, B28, W68, and W76 systems.

Pertinent Tasks

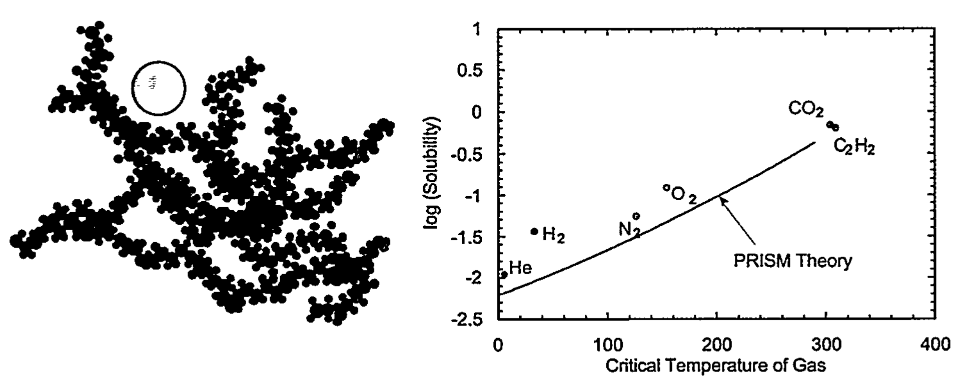
- **SN07** Degradation of Materials in Electromechanical Devices
- **SN05** Organic Materials Predictive Capability
- **SN04** Predictive Capabilities for Long-Term Aging of Energetic Materials in weapons
- **SN01** Degradation of Materials in Electronic Devices
- **SN06** Ceramic Materials Predictive Capability
- **SN03** Stress Voiding of Integrated Circuits
- **SN02** Materials Interface Issues

More Reliable Predictive Aging Methods for Polymers

Since the lifetimes of weapons are being extended to several decades, it is important to develop superior methods for assuring the long-term reliability of weapon components. We have been working on several approaches that allow more confident predictions of component lifetimes to be made for polymeric materials exposed to air (i.e., oxygen-containing) environments. These methods have been tested on an O-ring material, which is utilized as the environmental seal in several weapons, including the W62, B83, W84, and W88. The results indicate with great confidence that these O-rings should perform adequately in weapon environments for a minimum of several hundred years.

Many of the technical advances developed under this program and underlying these more confident O-ring predictions are of general enough utility to be applicable to many other polymeric materials. These advances include the following:

- Development of theoretical models for diffusion-limited oxidation (DLO) effects that often complicate attempts to understand the effects of environmental stress (e.g., elevated temperatures) on accelerated aging experiments.
- Use of modulus data from our unique modulus-profiling apparatus (50 micrometer resolution) to quantitatively verify the theoretical DLO models, allowing us to confidently predict the importance of DLO



$$S = \frac{(1-\eta)}{4\rho_m kT} \exp\left[-(\mu_A + \mu_H)/kT\right]$$

$$D = D_o \exp\left[-(\mu_A + \tfrac{1}{2}\mu_H)/kT\right]$$

Figure SN05. *Insights into gas permeation, oxidation, and diffusion-limited oxidation provided by theory are important in determining the useful life of weapon polymers.*

effects on accelerated aging conditions before experiments are initiated.

- Development of the first method that allows a quantitative test of the often-used assumption that Arrhenius behavior, found under accelerated aging conditions, can be extrapolated to the much lower-temperature (longer-time) use conditions. This method involves the use of ultra-sensitive oxygen-consumption measurements made both at high temperatures to establish their correlation with conventional accelerated aging data, and at the lower temperatures corresponding to the normal extrapolation region.
- Developing a "wear-out" approach for predicting the remaining lifetime of polymer materials by borrowing ideas from cumulative damage models, which have been applied extensively to fatigue loading of metals, composite materials, etc. For our application an environmental variable, temperature, replaces the mechanical stress or strain variable, and time replaces the number of fatigue cycles. In the simplest case of constant chemical acceleration, corresponding to time-temperature superposition of polymer degradation, a linear wear-out model is predicted.

The advances in understanding and predicting aging are of general utility to weapon-aging problems and to aging problems of interest throughout government and industry. The oxygen consumption approach represents the culmination of a 50-year search for a viable extrapolation-verification technique. This approach and the DLO models are currently being used for (1) predicting safety cable lifetimes in nuclear power plants and (2) understanding the dominant reaction mechanisms in an important industrial component (with a partner under a Cooperative Research and Development Agreement). The potential viability of the wear-out approach for O-ring materials has been verified using samples aged under high-temperature conditions. We are currently working with surveillance groups and Pantex to obtain W62 O-rings that have been field-aged for periods up to approximately 20 years. These O-rings will allow us to test the wear-out concept on actual field specimens and to verify our accelerated aging predictions of very long lifetimes.

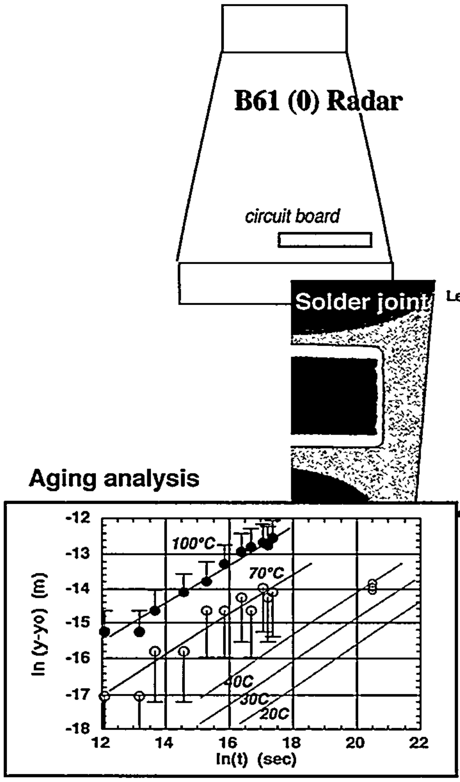
SN01 Degradation of Materials in Electronic Devices

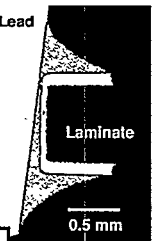
Through the surveillance of actual stockpile hardware, anticipated aging mechanisms can be documented and compared against earlier predictions. The effects of complex materials interactions and storage environments that would have been difficult to predict at the time of component design become readily apparent. The validation of predicted aging processes and unveiling of unexpected aging mechanisms can be used to further the critical analysis of the present stockpile for lifetime-extension activities.

An area of concern in the aging of nuclear weapons is the integrity of the solder interconnects used in the electronic components because the functionality of all weapon systems depends upon the integrity of their electronics. Methodologies have been developed that systematically examine the microstructure of solder joints from dismantled weapon hardware. These methodologies are based upon quantitative metrics that serve to measure more precisely the extent of aging that has occurred in the interconnects. Once the history of the solder joints has been quantitatively described, this information, together with the same predictive models, is then used to determine the suitability of electronic components or systems for lifetime extension in the stockpile.

Aging degradation of Sn-Pb solder interconnects is apparent through changes to the microstructure of the joint. Those changes include a coarsening of the Pb-rich phase particles that reside in the Sn matrix. Extensive, localized coarsening of those particles is a precursor to the formation of fatigue cracks that can cause functional failure of the joints and hence, failure of the electronics. The coarsening phenomenon is a function of temperature, time, and mechanical stress.

A second metric of solder joint aging is a growing thickness to the intermetallic compound (IMC) layer that forms between the Sn-Pb solder and the conductor substrate. An overly thick layer can result in a progressive fracture of the solder joint. Excessive IMC growth occurs at the expense of substrate material, thus jeopardizing the ability to replace solder interconnects following component exchange or repair. The IMC layer growth is largely dependent upon the service temperature and time. The capability to quantify the microstructural properties





of the solder interconnect, which are at the heart of these failure scenarios, provides an important tool for predicting the reliability of extended-use hardware as well as determining the service performance of replacement hardware.

The B61 (0) tube-type radar units were targeted for lifetime extension in the weapons stockpile. A particular concern was the reliability of the solder interconnects used to assemble the system electronics. A study was initiated to examine solder joints from field-return hardware. The objective of this evaluation was to determine the suitability of the solder interconnects for an additional 20–25 years of stockpile service.

A number of different tests taken together showed that a relatively modest degree of aging had occurred to the interconnects over their 30 year lifetimes. Extending the quantitative models to predict changes to the solder joint microstructure for a lifetime extension of 20–25 years did not indicate a degree of degradation that would significantly impact the functionality or future repairability of the solder joints in the B61 (0) radar units.

Figure SN01. *Stockpile hardware provides basis for solder-joint-aging predictions.*

Energetic Materials Area

In this program element, we strive to understand the aging of explosives. Energetics are logical targets for the study of lifetime extensions because of the amount of energy they store and their continued high safety and reliability if their components fail. Several key components use pentaerythritol tetranitrate (PETN) and PETN blends as their energetic materials.

The MC2370 (from the dismantled W68) and the nearly identical MC3028 (from the W76) are firing sets that rely on the explosive output of PETN. Explosive output and simultaneity are critical for successful function. Though no problems relating directly to energetic materials have been discovered in existing components, time-dependent changes (chemical or physical) could cause a future malfunction. The PETN explosive has been widely studied, but published activation energies for its decomposition vary by >40 kcal/mol. This huge range reflects a poor understanding of the autocatalytic decomposition process. Additionally, the literature supports a sudden failure curve for PETN, so we must understand the mechanism and rate of any ongoing aging before meaningful recommendations for lifetime extensions can be made.

Novel Analytical Methods

To identify many thermal and chemical degradation products of PETN, we combine studies of PETN that has been isotopically labeled with chromatographic techniques.

- Capillary electrochromatography using ion-trap mass spectrometry (CEC/MS) detection has been pioneered at Sandia. CEC/MS complements liquid chromatography with negative chemical ionization mass spectrometry (LC/MS), yielding two extremely sensitive analytical tools that elucidate the structures of PETN decomposition intermediates.
- We have demonstrated that different chemical conditions (acidic, oxidative, hydrolytic, and basic) yield the same primary decomposition product by cleaving one of the nitrate esters (compound 4 in the figure) and that higher-temperature, solid-phase thermal aging rapidly yields a larger number of compounds. Having identified these decomposition products, we can look to the stockpile for markers of aging phenomena.

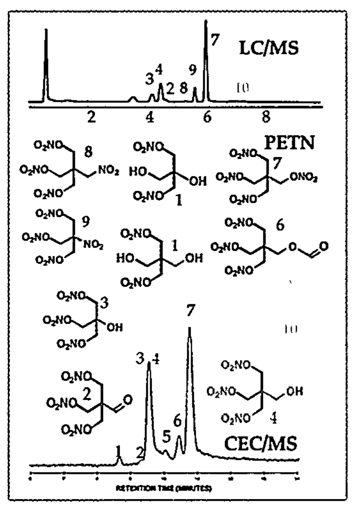


Figure SN04. *A comparison of CEC/MS and LC/MS chromatographic analyses of aged PETN.*

SN07 Materials Aging Modeling: Lubricants

Molybdenum sulfide (MoS_2) is the primary constituent of a solid lubricant used in weapon electromechanical assemblies and is known to degrade by oxidation. Gas sampling of aged stronglinks has shown that these devices often contain some oxygen and/or water vapor, even in packages designed to be hermetically sealed. A predictive capability for lubricant performance based on aging environment and time is needed to assess the impact of stockpile life-extension on stronglink reliability.

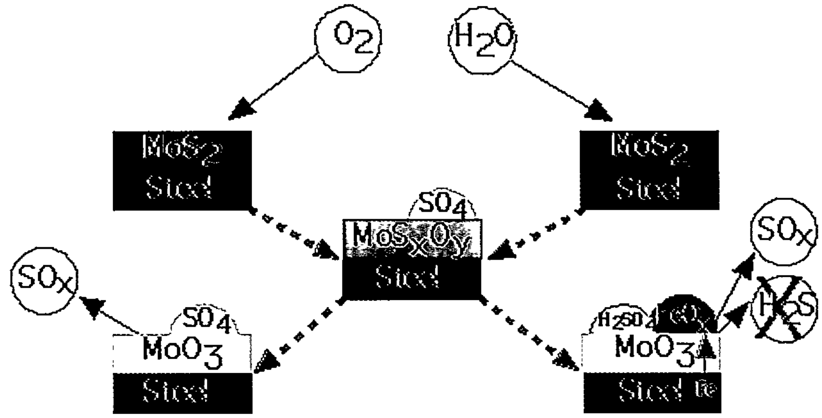


Figure SN07a. *Proposed reaction pathways for oxidation of MoS_2 and the substrate.*

The goal of this project is to develop tools for predicting the performance of lubricants after long-term exposure to conditions in the stockpile. Water vapor, type and amount of substrate material at the surface, and the presence of other adsorbates alter the degradation kinetics and performance of solid lubricants. The relative importance of these factors in lubricant oxidation must be determined so that the kinetics and performance impact can be evaluated. Oxidation and tribological* per-formance data are used to develop materials models that can be used in dynamic simulations of stronglink performance to evaluate the significance of changes in material behavior on the operating characteristics of the device.

Studies of MoS_2-containing solid lubricant show that this material has a low activation energy for oxidation. The rate of oxidation is not strongly affected by the amount of water vapor present or the type of substrate or temperature, but these parameters do impact the chemical species formed during oxidation. Reaction pathways between the lubricant, substrate, and gases are shown in Figure SN07a. Reaction of the lubricant with oxygen produces surface sulfates and may result in a reduction in total sulfur by volatilization of reaction products. When water vapor is present, sulfates react with water to form corrosive products that can attack exposed substrate and cause formation of metal oxides at the surface. These reactions have the potential to dramatically change the sliding friction behavior of the surfaces. Analysis of the sliding friction behavior of oxidized surfaces revealed that most of the impact resulting from lubricant oxidation was manifested as changes in the initial friction coefficient.

Wear of the oxidized material caused the friction coefficient to return to preoxidation levels within several contact cycles. However, higher friction for just a few operating cycles can significantly alter device performance. Figure SN07b shows that a correlation exists between the initial friction coefficient and sulfate concentration, with initial friction increasing as the amount of reacted sulfur on the surface increases. Reaction of sulfur with oxygen and water vapor destroys the low-shear microstructure present in the virgin solid lubricant and results in increased friction.

This information can be used to predict the initial friction behavior of the solid lubricant given the aging environment. The performance impact of the lubricant on the complete assembly, based on various storage scenarios, is now being assessed.

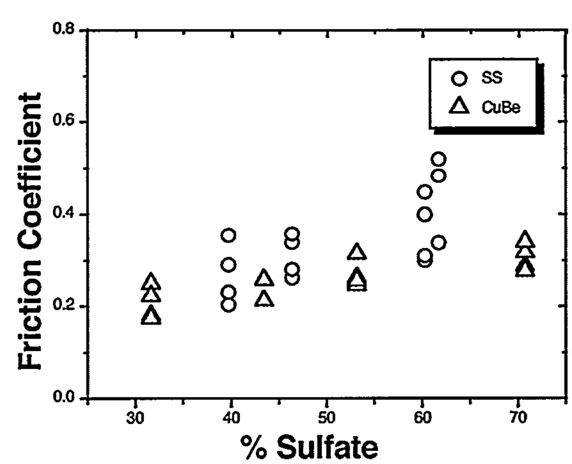


Figure SN07b. *Dependence of initial friction coefficient on surface sulfate concentration.*

*(friction, lubrication, and wear of surfaces in relative motion)

Nonnuclear Components

Rationale

The fundamental objective of the Nonnuclear Components Focus Area is to provide improved information and tools to support stockpile management decisions for the enduring stockpile. Historically, surveillance of nonnuclear components and subsystems has been based upon system-level functional testing. While such system-level testing will remain as the principal method of nonnuclear surveillance, such performance testing is forensic rather than predictive in nature—failures are found, but early indicators of unacceptable changes are generally not observable. This focus area is designed to increase our ability to monitor, anticipate, and manage time-dependent changes in nonnuclear components that would otherwise pose high risks to stockpile management. It will link together information about the aging of weapon materials with understanding of the performance margins of such nonnuclear components to enable a predictive understanding of the future evolution of nonnuclear components in the stockpile. This program is intended to identify the time scale to loss-of-confidence in nonnuclear components and subsystems and to provide component-level surveillance methods and recommendations geared to discovery of changes before unacceptable performance degradation occurs.

Purpose

There are more than 200 major nonnuclear components and subsystems and literally thousands of supporting piece parts. These components (and subsystems) have been prioritized in order to assess and manage risk across the stockpile. The highest-priority components for enhanced surveillance studies were selected on the basis of their pervasiveness in the stockpile, their effect on reliability and safety, and the likelihood that problems with their materials would occur. The initial prioritization, performed in FY96, will be reviewed and revised on a regular basis as increased information on component-level risks is available. There are presently three tiers of nonnuclear component priorities. Tier I has 14 components that pose the highest risks to the stockpile, Tier II contains 35 components with substantial risks, and Tier III lists the remaining 150+ components. It should be noted that meaningful life-extension decisions of Tier III components would still require some R&D.

There are three major classes of nonnuclear components and subsystems: electronic components and subsystems, electromechanical components, and components and subsystems containing energetic materials. Work performed within the ESP is organized into three tasks, each representing one of these major classes of components. Objectives of these tasks are to assess existing component degradation information, develop predictive component-degradation models that can be used to predict the system reliability over time, recommend and develop additional component-level surveillance methods, and guide future stockpile decisions regarding component replacement.

1. **Electronic Components and Subsystems** - Stockpile components in the electronic components and subsystems category include programmers, electronic component assemblies, firing set electronics, and the microelectronics, resistors, inductors, and transistors that make up the larger assemblies. These components perform a variety of functions in nuclear weapons and, in some cases, a failure in one of them would result in failure to provide the firing signal to the nuclear package detonators. Likely failure mechanisms for these components range from degradation of solder joints to damage of electronic piece parts as a result of stress voiding and ionic contamination. The approach taken in this task is to determine which electronic components are most important to the subsystem function, determine the critical phenomena that control the aging characteristics of these components, study these effects, and develop models of the components based on scientific approaches. These models will be integrated into age-sensitive subassembly models and, finally, age-aware weapon system models. These steps will involve analysis of returned stockpile hardware and detailed understanding of materials.

2. **Electromechanical components** - Electromechanical components in nuclear weapons are fundamental to reliability and nuclear safety. Over 120 components in the stockpile are in this category and include strong links, environmental sensing devices such as accelerometers and decelerometers, trajectory-sensing signal

generators, rolamite mechanisms, and switches. These devices may fail as a result of age-related degradation of mechanical movements, fluid characteristics, or electrical contacts. They may experience changes in friction resulting from contamination or corrosion, or decreases in lubricity. Electrical resistivity may increase as a result of corrosion or organic deposits on contacts and degradation of solder and wire bonds. Improper sensing of acceleration may occur as a result of loss of fluid, fluid parameter changes, changes in the spring constants of accelerometers, or changes in device friction. Many of these potential problems are associated with oxygen or moisture being admitted to the device.

3. **Energetic Components** - Components containing energetic materials can be classified into two groups: 1) thermal batteries that contain igniters to initiate battery activity, energetic materials to provide thermal energy to bring the battery to its operating temperature, and reactive chemicals ($Ca/CaCrO_4$ and $Li(Si)/FeS_2$), which produce the required electrical energy; and 2) explosive components such as explosive firing sets, detonators, piston motors, spin rocket motors, explosive actuators, igniters, gas generators, and timers, all of which rely directly on the ability of the explosive or pyrotechnic that they contain to perform an electrical, mechanical, or timing function. The approach taken in this task is to determine the critical parameters and phenomena that control the aging characteristics of these components, study these parameters and phenomena, develop and validate models of these parameters and phenomena based on the scientific understanding gained, and incorporate the results of these models in age-aware subassembly and finally age-aware weapon system models.

A separate task within the Nonnuclear Components and Subsystems Focus Area is the Aging and Nuclear Safety Evaluation Task. Its purpose is to ensure that no safety-critical components will fail in an unsafe manner because of aging. This goal will be accomplished by identifying potential age-induced degradation that would impact the nuclear safety of stockpile systems, verifying and assessing degradation mechanisms, recommending procedures by which surveillance programs can detect degradation, and developing projects to evaluate potential age-induced degradation. This resulting knowledge will be evaluated for nuclear safety by a team consisting of systems personnel, nuclear safety engineers, component owners, and materials scientists.

Expected Outcome

This focus area is intended to develop recommendations and methods for augmentation of the core surveillance program to include targeted component-level testing of high-risk components and to develop age-aware subsystem and component models that can then be used to predict system lifetime reliability. The focus area also provides the critical linkage between assessments of time-dependent changes in materials (performed within the Nonnuclear Materials Focus Area) and the consequence of those changes to system surety and reliability. This effort will provide important elements of the technical basis for the risk-management decisions that will be made within the Stockpile Life Extension Program, specifically by providing estimates of appropriate replacement intervals for high-risk components and by supporting decisions about other component retrofits needed when a system is returned for changes.

Deliverables

1. Publish final report on component prioritization.
2. Apply fault-tree methodology to stronglinks and rolamites.
3. Compare diagnostic test data from B28 MC2969 stronglinks (10 to 13 years old) and from B61-5 MC2969 stronglinks (18 to 20 years old) with original production data to identify indications of degradation.
4. Develop a dynamic model of the MC2969 escapement mechanism and perform device simulations using quantitative constitutive relations for lubricant performance as a function of time and environment.
5. Identify interfacial degradation in the SFE output stack in the MC2370 firing set.
6. Establish which diamond-stamped W76/W78 SFE firing sets destined for rebuild activities meet minimum performance requirements.
7. Perform a detailed simulation of the XTX burn in several output pellets of the SFE explosive lens, and generate MPEG movies of the explosive burn processes.
8. Obtain evidence that normal degradation of the main capacitor in the W76 trigger circuit will not affect the normal operation for 100 years.
9. Develop and validate a functional model of the MC2918 CDU firing set, and complete sensitivity analysis.
10. Develop methods to automate the accelerated aging, testing and modeling of discrete semiconductors and linear integrated circuits in the MC2918 firing sets.
11. Complete an electronic component sensitivity analysis for the TSSG.
12. Conduct final review of nuclear safety critical components and materials in the W76.

Pertinent Tasks

- **SN27** Enhanced Surveillance of Components and Subsystems Containing Energetic Materials
- **SN23** Age-Induced Degradation of Nuclear Safety/ Nuclear Safety Degradation
- **SN24** Component Prioritization and Project Management
- **SN25** Electromechanical Component Modeling
- **SN26** Enhanced Surveillance of Electronic Components and Subsystems
- **OR11** Arming, Fuzing, and Firing Shields

Electromechanical Components–MC2969 Stronglink

Nuclear weapons contain electromechanical components fundamental to nuclear safety and weapon reliability. "Stronglinks" are among the most complex of these critical electromechanical components in the enduring stockpile today. They prevent energy from reaching the firing set until predefined, unique signals are received. We will create age-aware models of critical portions of the MC2969 stronglink as a step toward predictive reliability of the stockpile and establishing focus for the Stockpile Life Extension Program to concentrate resources on the most important stockpile issues. These age-aware models will incorporate the results of materials-aging models and use the understanding gained from stockpile surveillance and the analysis of returned hardware for validation. The output of these models will be compatible so that each model's results can be used in higher-level assembly models. This task is an essential step in linking materials-aging to future stockpile reliability.

Efforts to date have been primarily focused on two areas:

- Evaluation of aging on the lubrication used in the escapement assembly. This study applies to all stronglinks and verge escapement environment sensing devices in the stockpile.
- Evaluation of MC2969s of dismantled B28s and B61-5s returned from the field.

Previous empirical studies show that device performance depends critically on lubricant effectiveness. On the MC2969, the escapement is very sensitive to friction changes and is therefore an excellent place to examine the effects of lubrication changes as a result of aging. In addition, we can compare data obtained from diagnostic tests initially run during production with data taken on the same units returned from the field.

- Diagnostic test data are being compared on B28 units (10 to 13 years aged) and B61-5 units (18 to 20 years aged) with the original production tests to check for indications of degradation.
- We are modeling the key portion of the escapement mechanism, the pallet and starwheel. We are using a dynamic modeling approach to utilize friction parameters developed by the Sandia materials organization. They are studying the effects of oxidation rates on numerous sets of escapement assemblies and providing the age parameters to the dynamic model.

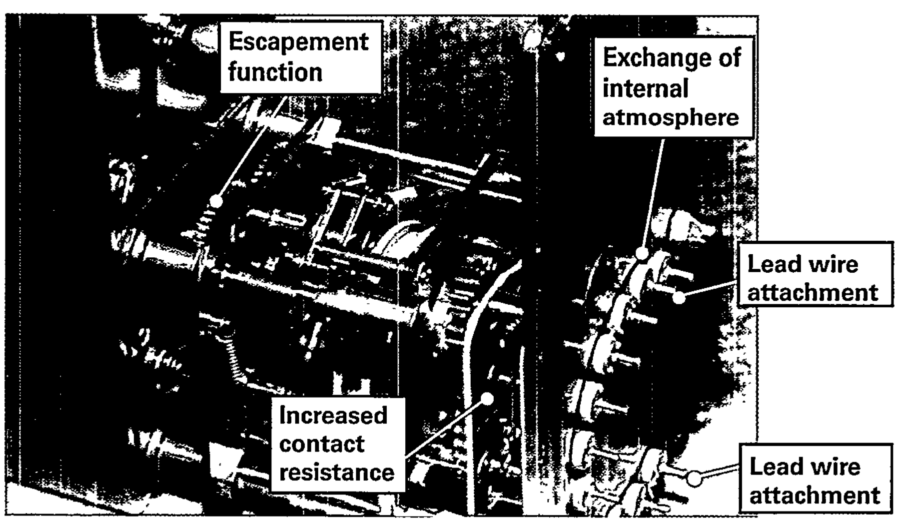


Figure SN25a. *Potential aging mechanisms of the MC2969 stronglink switch.*

Most of the 31 dismantled B28 MC2969s have been fully tested at AS-FM&T, and data reduction has begun. Allied Signal has begun testing three B61-5 units, and another eight are ready to be tested.

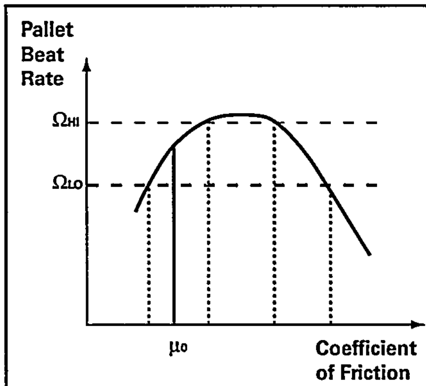
Relying on the production data to guide us, we see from preliminary results degradation or concerns in several areas:

- Exchange of internal atmosphere,
- Increased contact resistance,
- Firing-set-to-stronglink lead-wire attachment,
- Escapement function (part of lubrication study at this time), and
- Electrical feedthrough ceramic fracture.

What we know now:

- Most of the observations can be explained as built-in problems or handling damage.
- All of the observations can be interpreted as age-related failures.
- No root causes for any of the observations have been determined.
- It is premature to make any conclusions about the stockpile based on our observations to date.

To rule out possible failures introduced by the dismantlement process, vibration monitoring of this process has been performed. We have determined that the vibration levels associated with component extraction are not sufficient to introduce damage.



- As the coefficient of friction increases from the nominal value, so does the oscillating frequency of the pallet.
- The pallet must oscillate in a frequency range so the MC2969 does not mistake short and long pulses.

Figure SN25b. *The effect of friction on the timing of the MC2969 stronglink.*

SN27 Enhanced Surveillance of Components and Subsystems Containing Energetic Materials

The objective of this task is to create age-aware models of critical energetic weapon components and subsystems to improve the ability to anticipate and manage performance issues in the weapon stockpile. These models should provide information about the possibility of life-extension of a particular weapon or component. The models will incorporate the results of materials-aging models with understanding gained from stockpile surveillance and returned hardware analysis where appropriate. They will also provide results that can be used in higher-level assembly models and will be validated with hardware and data. This task will lead to essential knowledge linking technical data from materials aging to future stockpile reliability.

The MC3028 slim loop ferroelectric (SFE) firing set fires the neutron generator and main weapon detonators on the W76 and W78 weapons. The device is a nearly exact derivative of the MC2370 SFE firing set used in the W68. Using W68 SFE firing set hardware, available from the dismantlement activities at Pantex, we have begun creating a database of the operational characteristics of the W68 firing set. This database will be used to validate a complex computer model of the SFE firing set currently being created for computational solutions on the "ASCI Red" massively parallel computer. The computer model will be able to replicate the electrical output of the MC3028 as a function of several input parameters and will reflect the effects of aging of internal MC3028 subcomponents. The project has an intermediate goal of a fully functional "age-capable" model by the end of FY97 with a complete "age-aware" model by the end of FY98.

The major accomplishments for this fiscal year are as follows:

- We developed the first meshed description of a quarter cell of the explosive lens for computation on an engineering workstation. The explosive lens consists of three materials with widely differing chemical properties.
- We analyzed the nonexplosive portion of the MC2370 firing set to reveal that the diagnostic electrical properties measured at the time of production had shifted significantly. Explosive testing of the same components showed a correlation between those units whose properties had shifted dramatically and low output-current measurements.
- We used the history-variable reactive burn model for XTX in the explosive tracks in a quarter section of track plate to demonstrate the sensitivity

of sustained propagation of the burn to material parameters.

- A detailed simulation of the XTX burn in several output pellets of the output plate of the explosive lens shows the same kind of asymmetry observed during production testing of the lens. This comparison lends credence to the calculations and is an important step in validating the burn model.
- We generated MPEG-format movies of the explosive burn processes. These movies allow us to quickly identify anomalous burn behavior.

A multidisciplinary team within Sandia is pooling its efforts to create a comprehensive age-aware model of the MC3028 SFE firing set to estimate the lifetime of these stockpile units in much more scientific manner than is currently available to us.

Component Prioritization and Project Management

The Nonnuclear Component Focus Area will provide an understanding of weapon system aging based on integrated knowledge of component design and design margins weighed against system requirements, in addition to materials-aging issues.

This program element develops tools, techniques, and models that will provide advanced capabilities to measure, analyze, calculate, and predict the effects of aging on nonnuclear components. This information will be used to understand the safety, reliability, and performance of existing weapons beyond their original design life.

The nuclear weapon stockpile contains dozens of subsystem types and thousands of components. Each of these devices has a *likelihood* of failure and *consequences* of failure. We cannot assess each of these parts simultaneously; consequently, we have prioritized our work. We have focused on a few of the devices that are most likely to fail and that have the most serious consequences of failure.

A team of six component engineers and weapon operation analysts has studied and prioritized all the major components in the stockpile. This group collected information about design and production issues, materials concerns, and stockpile surveillance data from the engineers and managers responsible for each component. All the components were then evaluated in five categories based on the impact of their potential malfunction in these categories:

- safety,
- reliability,
- use control,
- their persuasiveness in the stockpile (the number of warheads in which they appear), and
- Operational importance of the weapons systems in which the component appears based on interactions with the military service customers.

The components were sorted against these criteria in various ways. For instance, when we sorted them primarily against their impact on safety and then against pervasiveness, we found that the prioritization done in this way was robust—the same components appeared high on the list regardless of the exact order in which the criteria were applied. The outcome of the process was a prioritized grouping of components into three tiers (see Figure SN24).

A prioritization methodology was developed and described in a final report, a listing of all major components in the stockpile was created, and an assessment of consequence and likelihood of failure was assigned to each.

The results of component prioritization guided resource allocation to study the following components selected from Tier 1.

- MC2969 Stronglink
- MC3028 Slim-loop Ferroelectric Firing Set
- MC2983 Trigger Circuit
- MC2918 Capacitive Discharge Unit Firing Set
- MC2854 Environment Sensing Device (fluid filled accelerometer)
- MC2897 Environment Sensing Device (escapement decelerometer)
- MC3268 Trajectory-Sensing Signal Generator
- MC2936 Thermal Battery
- MC2823 Radar

As issues associated with the aging of components, subsystem, and materials are studied and better understood, modification of these priorities will occur through further reviews.

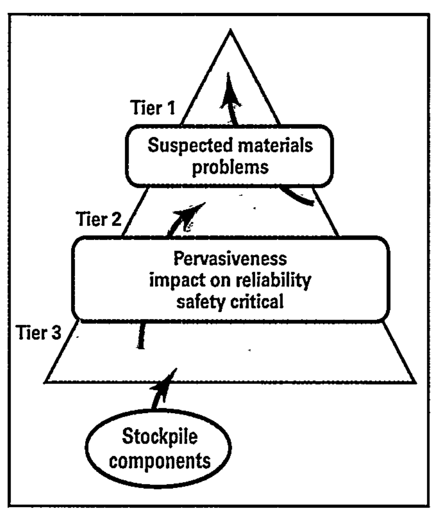


Figure SN24. *Component Prioritization Process.*

SN26 Capacitive Discharge Unit Firing Set

We are developing the tools needed to predict the future performance of firing sets beyond their original design life. As stockpile components age, there is a need to rapidly evaluate and manage the potential impact on weapon readiness resulting from device and material degradation. New analytical and evaluation tools are required to enable informed decisions. These tools include advanced circuit simulation, improved physics-based device models, statistically derived sensitivity analysis of firing set components and materials, accelerated aging tests of electronic devices, and improved core surveillance data acquisition and trend analysis. These tools will enable the early identification of performance trends and potential concerns with specific devices and materials.

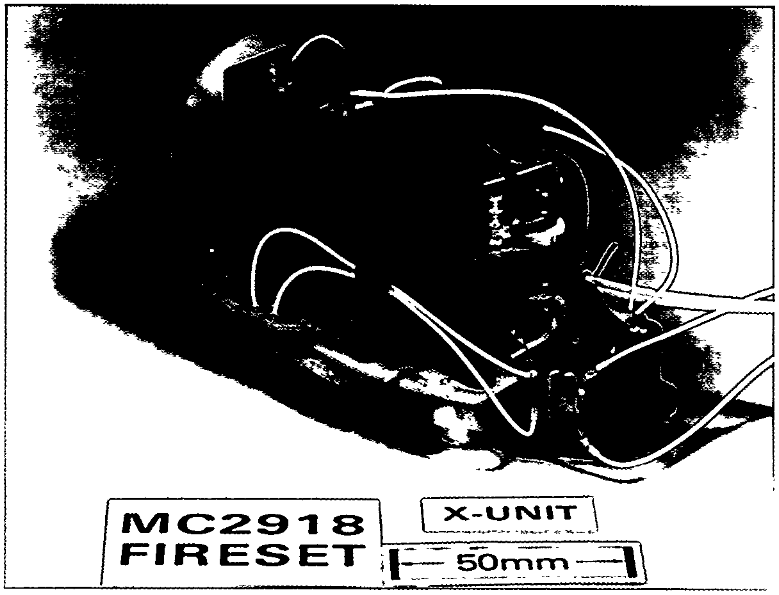


Figure SN26. *The capacitor component of the MC2918 CDU firing set.*

The MC2918, a capacitive discharge unit (CDU) firing set, is representative of CDU firing sets in six of nine enduring stockpile weapons. There are four elements of this project:

- The evaluation of aged stockpile hardware to identify potential material, mechanical, and electronic device degradation.
- The development of accelerated aging tests to apply controlled aging stress to electronic devices.
- The development of advanced circuit simulation, device models and analytical tools.
- The development of improved core surveillance data acquisition and trend analysis.

Accomplishments in these areas follow.

- In collaboration with Pantex and AS-FM&T, we have developed nondestructive processes for the recovery and scientific evaluation and analysis of aged stockpile firing set materials and electric components from dismantled stockpile weapons. Materials investigations include the soldered connections on one of the oldest flat-pack integrated circuits in the stockpile and the ceramic-to-metal seals on the firing set high-voltage sprytron switch. Thirty-six of nearly two hundred available stockpile firing sets, eighteen to twenty years old, are being disassembled for study in FY97 and FY98.
- We have developed improved accelerated-aging test methodologies including a screening test to evaluate the susceptibility of electronic devices to low-dose rate radiation degradation and a method for the automated acquisition of device parameters. Accelerated-aging tests will extend the aging process of electronic devices beyond currently available hardware; identify performance margins, failure limits, and failure mechanisms; and provide the data needed to develop accurate device models for physics-based circuit simulation.
- By applying advanced circuit-simulation techniques, we have identified the most significant components that affect the performance of the MC2918. This accomplishment will allow us to continue to pursue accelerated-aging studies of the proper components in the coming fiscal year.
- We have initiated development of material-level age-aware device models for the classes of electronic components that impact firing set performance.

In FY98 and FY99 the data acquired from stockpile hardware evaluation and accelerated aging tests will be integrated with the modeling techniques necessary to develop an accurate predictive simulation of the MC2918 firing set.

Routine Surveillance Testing Systems Upgrade

Focus Area

Rationale

The nuclear weapons complex (NWC) laboratories and production agencies support their stockpile stewardship through the integration of enhanced techniques into the routine surveillance testing program. Impacting the current program with new techniques and technologies will result in the NWC's ability to identify failure mechanisms that are of interest in an ever-aging stockpile. As such, tasks related to this activity are specific to affected areas and provide coherence only through their augmentation of the core program.

Purpose

The purpose of the tasks is to meet the needs of the individual agencies while developing ongoing capabilities and resources within the NWC. Affected core surveillance information and systems developed in this effort provide enhanced understanding of the nuclear weapon stockpile. For descriptions of individual agency efforts, refer to the individual task

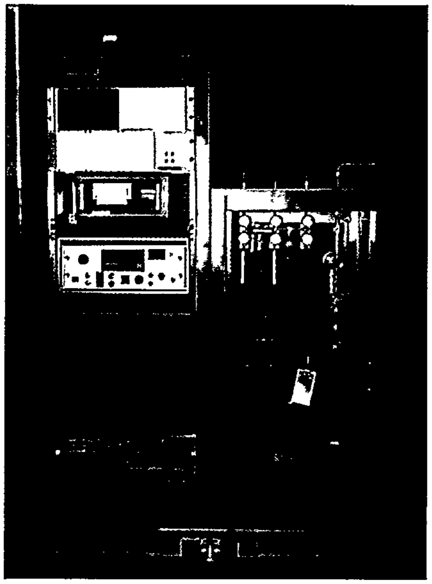
Deliverables

1. Augmented core surveillance program available at Oak Ridge and Pantex to monitor war-reserve, canned-subassembly roll-rate decay by FY99.
2. Augmented accelerated aging unit (AAU) tests that provide enhanced data and an understanding of age-related mechanisms by FY99.
3. Augmented gas analysis technique, Phoenix, and Field Sampling Unit that provides valid dew-point and humidity measurements for understanding the stockpile an d replacement interval for desiccant as early as FY97 with extended capability and trend analysis by FY99.

Pertinent Tasks

- **OR08** Air-Bearing Technology Transfer
- **PX07** Air-Bearing Technology Transfer
- **SN16** Validation Test Suite—AAU Program Development for Robust Testing
- **SN17** Advanced Diagnostic Methods (Blue Goose Replacement)

SN17 Weapon Internal Gas Sampling: The Phoenix, the W80 Field-Portable Gas Analyzer (FPGA), and the AAU Gas Sampler



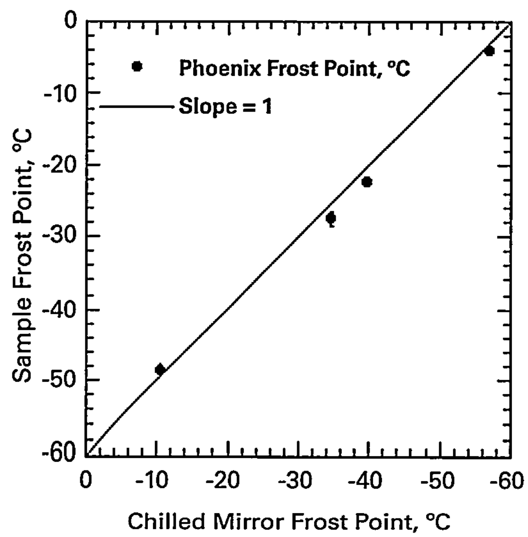


Figure SN17. *The Phoenix gas sampling cart at Pantex yields accurate frost-point measurements from static environments like those encountered in weapon internal atmospheres.*

Providing uncontaminated weapon internal atmosphere samples and measuring their frost points is of paramount importance for enhanced surveillance and accelerated aging. We are developing and integrating three types of gas sampling systems for use throughout the weapons complex. The Phoenix was developed and fabricated at Pantex and Sandia as a replacement for the antiquated "Blue Goose" gas sampling cart. The W80 FPGA was developed from the Phoenix concept and was fabricated at Sandia for measuring the frost point of W80 internal atmospheres in the field while providing the capability for capturing gas samples that could be further analyzed at Pantex for oxygen, nitrogen, argon, and other gases of interest. The accelerated aging unit (AAU) gas sampler was designed at Pantex and Sandia, is currently under fabrication, and will be used for obtaining internal frost points and weapon gas samples during the testing of AAUs.

Clear evidence exists that the "Blue Goose" gas sampling cart yields inaccurate frost point measurements that are much drier than those measured by water uptake from desiccants in the weapons. The "Blue Goose" uses long gas sample lines and antiquated gas handling technology, which contribute to these erroneous measurements. Further, the gas handling system in the "Blue Goose" could contribute organic contaminants to the gas sampling system. Using modern gas handling technology, dry pumping systems, and very short gas sample lines, we have shown that the Phoenix replacement for the "Blue Goose" can accurately measure frost points from static volumes (see figure above). Other accomplishments in these three companion projects include:

- Design of a balance arm for the Phoenix to relieve the weight of the Phoenix measurement system from the gas sampling valve on the weapon.
- Integration of the three gas sampling systems into the core and enhanced surveillance programs so that similar/identical gas handling technology is being utilized wherever possible.
- Drafting of documentation for the Phoenix and W80 FPGA to be used in weapon atmosphere sampling environments.
- Fabrication/procurement/assembly/testing/qualification of components needed to deliver four W80 FPGAs by October 1997 and two Phoenix gas carts by January, 1998.

These projects are collaborative efforts led by Sandia and involving all seven ESP Sites.

OR98 Y-12 Low-Level Vibration and Air-Bearing Testing

Low-Level Vibration Testing

The low-level vibration (modal) testing at Y-12 is used to determine the dynamic characteristics of weapon subassemblies. Such characteristics provide important information about parts internal to the subassemblies. Deterioration of internal components and component damage are detected from the dynamic characteristics. Some internal changes strongly effect external dynamics while other internal changes cause weak changes in the external dynamics.

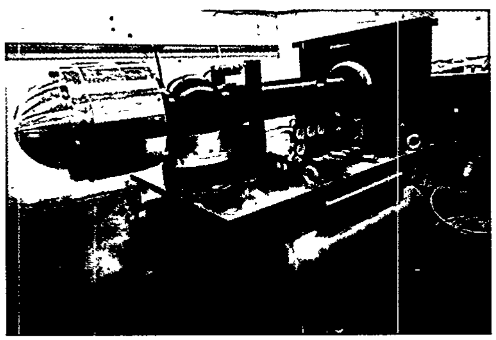


Figure OR98. *The air-bearing test apparatus with test object mounted for system checkout.*

Low-level vibration tests have been conducted on approximately 40 joint test assemblies and on 40 war reserve (WR) subassemblies. Tests have also been conducted on several older designs. These tests show large differences in the dynamics between older designs without cushions and new designs with cushions. Resonant frequencies and damping values of the new subassemblies are clearly related to cushion stiffness and damping. Repeated low-level vibration testing tracks cushion conditions as the unit ages. Changes in cushion properties change the resonant frequencies observed; increase in resonant frequencies implies cushion stiffening, decrease in resonant frequencies implies cushion softening, and an increase in the nonlinear behavior usually implies loss of the load placed on the subassembly when it was manufactured (preload).

During FY-1997 Y-12 achieved the following milestones:

- **Delivery and implementation of an improved low-level vibration test system.** A small (50-lb force) vibration test machine and associated test hardware were acquired. This machine allows vibration of suspended test items in a "free-free" configuration, where the test machine dynamics have a minimal effect on the dynamics of the test unit. Free-free testing is particularly effective with units like the W-76 and W-78. Tests using the larger 3000-lb force Y-12 shaker are effective with units like the W88, where significant external preloads must be applied.

- **Initial tests of WR W78s.** Low-level vibration tests have been conducted on three W78 subassemblies using the new 50-lb force test system. Procedures for conducting these tests have been written, fixtures constructed, and data analysis software qualified. Frequency response function and time series data were collected from lateral and torsional tests. Tests on six WR W78s have also been conducted at Los Alamos.

- **Purchase of Matlab analysis software.** Y-12 is purchasing Matlab software for data analysis. Los Alamos has several routines written in the Matlab language for analysis of the Y-12 test data. Initially the data will be run through the routines at Los Alamos. As Y-12 Matlab software becomes available, analysis will be done on the data on-site at Y-12. The Los Alamos Matlab software computes functions like the "bispectrum," nonlinear time series models, and the probability density function of the time series response.

Air-Bearing Test System

An air-bearing test system spins a test unit around an axis parallel to the floor at rotation rates between 0.2 and 2.0 revolutions per second. Since losses in the air-bearing system are quite low, the roll-rate decay is determined primarily by losses caused by moving parts inside the test assembly. Y-12 has purchased an air-bearing test system. Delivery is scheduled for early October of 1997. The air-bearing system has been received at Y-12. System checkout includes tests of the bare rotor system and a rigid test body. Following checkout, tests of the W-78 and W-76 will be conducted. Tests will be conducted jointly with Los Alamos personnel to ensure that consistent measurements are made at both the Los Alamos and Y-12 facilities.